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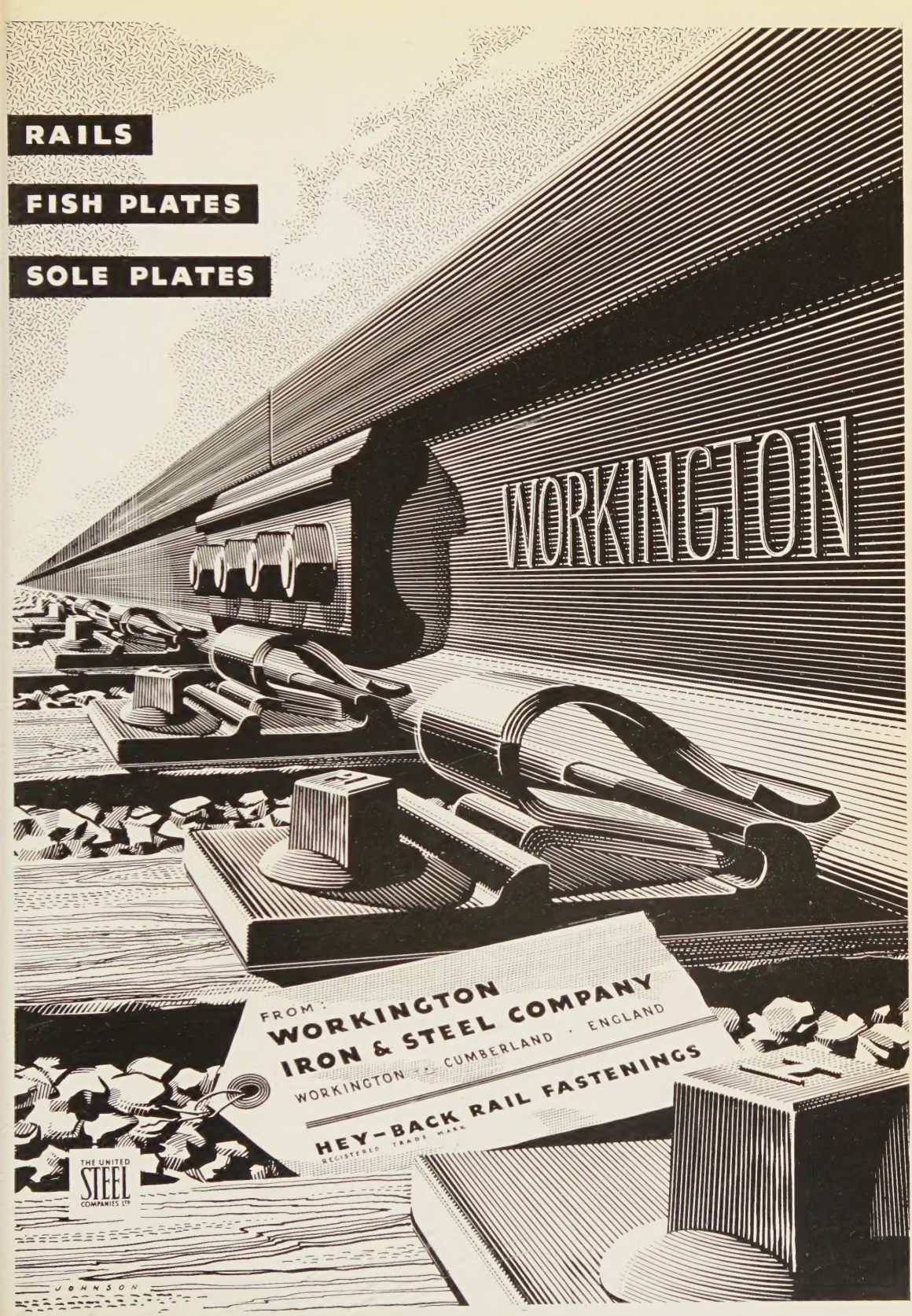
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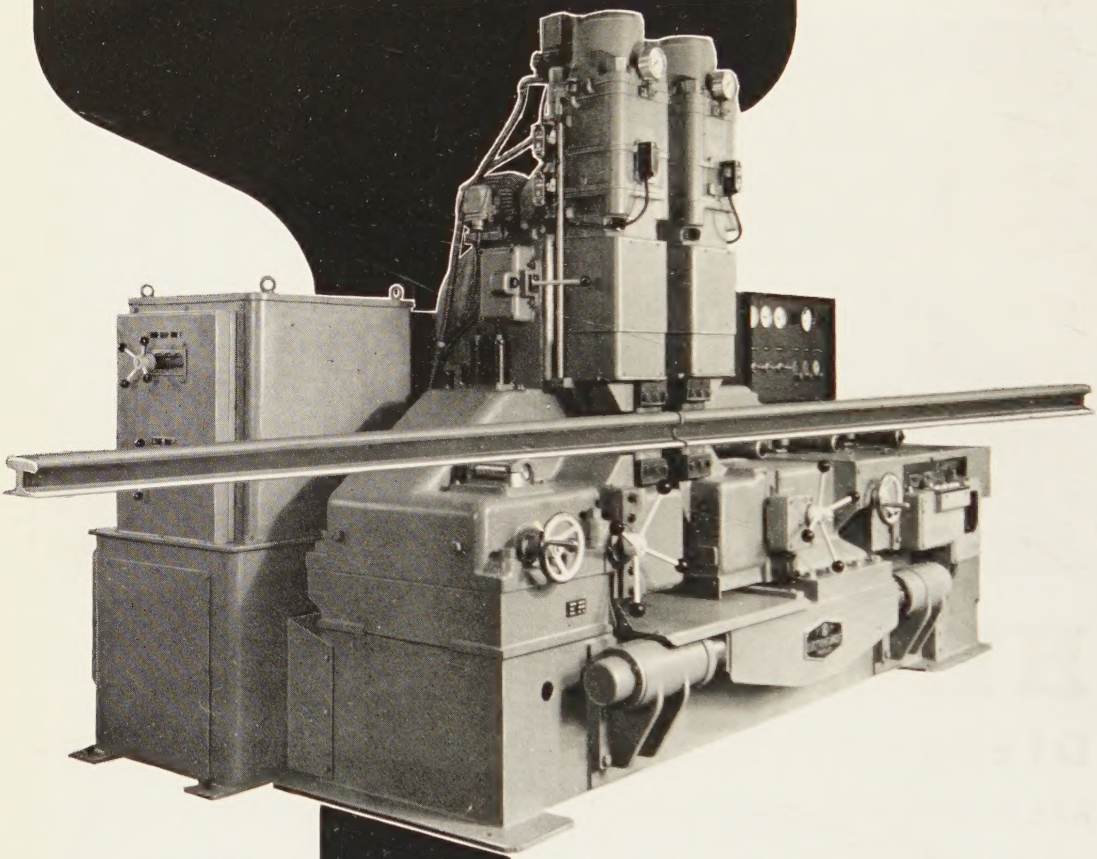

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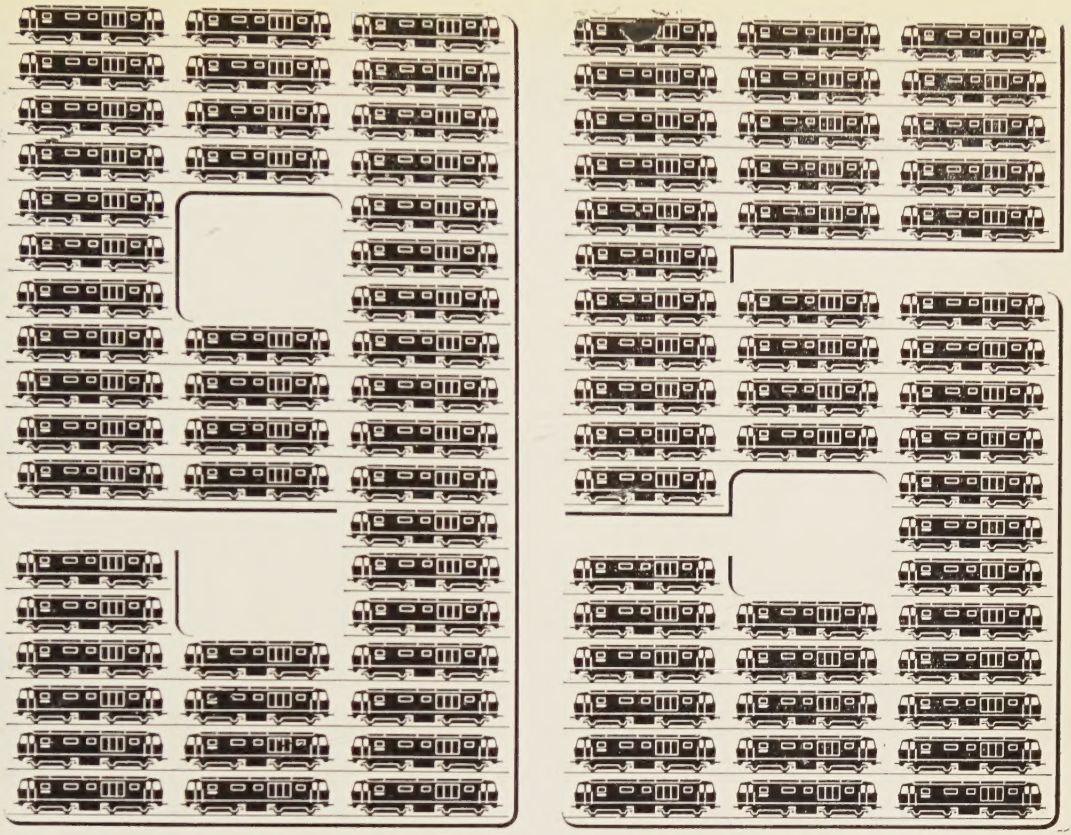

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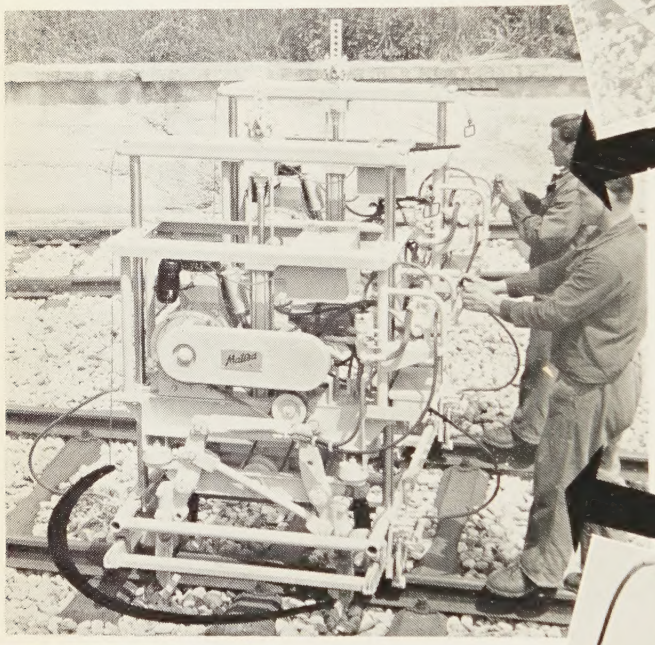

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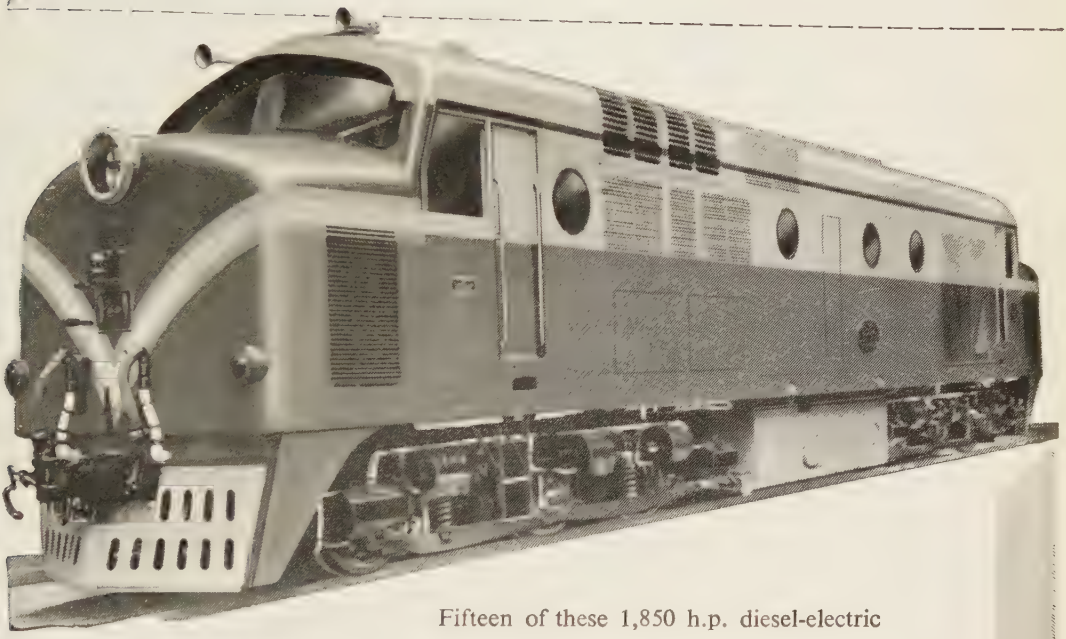

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On the Southern Region. Direct current third rail traction. Motor luggage vans with battery equipment. (800 words & fig.)

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BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[625 .25]

Disc brakes for railway vehicles and their linings,

by Dr.-Eng. F. Sauthoff and Dipl.-Eng. E. Schmidt, Minden (Westphalia).

(*Glasers Annalen*, Nos. 4 and 5, April and May 1959.)

1. Brief review of the evolution of the brake using composition linings for railway vehicles.

Alongside the brake with brake blocks acting on the wheels through cast iron brake blocks — the brake which may be considered as the classic type — the type of brake with composition linings has been applied more and more frequently on railcars since 1934. It has been used thereon in the form of drum brakes with exterior shoes and as disc brakes whilst the drum brake with inside shoes, the usual type on road vehicles, has never been adopted.

The first railway vehicle fitted with a drum brake with external shoes was the famous fast railcar the « Fliegender Hamburger » (1932). Even though the brake linings at that time left much to be desired, the experience acquired with this brake led to the adoption of the drum brake for the following series of fast railcars. Unfortunately, these gave less satisfactory results at first in ordinary running service. This was due on the one hand to the increased weight and as a result thereof to the increased power to be absorbed by the drums, and on the other to the fortuitous conjunction of unfavourable circumstances in the brake gears as a whole which whilst not concerning directly the drum brake, influenced its action. The newly designed details used in the compressed air parts, included in the transmission of the braking force and in the hand brake often caused trouble and irregularities in the brake gear installation with the result that the braking power might not be divided equally over all the brake drums, or that whilst running a brake band unwittingly might not be fully released and be rubbing lightly. This gave rise to smoking and smell with heavy wear of linings and even in serious cases to cracking and other damage to the drums as well as the destruction of the linings. The railcars of the Hamburg type when used on the north-south services also gave rise to particular difficulties through the high temperature set up when running over the gradients during the crossing of the Thuringer Wald, which made it necessary at the beginning to provide for short service stops at the end of the down gradients for testing the brakes.

Similar phenomena were experienced with the two or four axled railcars with drum brakes. In this case, the damage to the drums and linings was due less to the high speed and the weight but rather to an unsuitable construction of the drum, an insufficient number of brake drums and to linings of insufficiently good quality. Fitting drum brakes (of very light design) on a considerable number of

express coaches ended in a characteristic set-back because the quantities of heat produced in common user service could not be dissipated. Consequently, the vehicles had to be altered to brake blocks. On the other railcars and express railcars, the improvement resulting from a detailed investigation into the design of the brake drums [2] (*), the perfecting of the linings [8] and the elimination of the other defects in the brake equipment, the training of the staff and their habituation in its use, resulted progressively in procuring satisfactory working.

About the same time as the drum brake without outside bands was made satisfactory, the work on the disc brake was taken in hand. Although its marked superiority over the drum brake as regards heat dissipation was made clear very quickly, it had been little used in the construction of new vehicles.

In the beginning, the best known vehicles were the Henschel-Wegmann (1935) and the Diesel hydraulic panoramic railcar (1935). The superiority of the disc brake — but also it is true the progress made in the technique of the linings — showed itself in a particularly clear way during a trial run with a high speed railcar of the Hamburg type equipped with new bogies with disc brakes on the west down grade of the Arlberg in 1939. The reduction in speed on the 25 km long gradient with an average declivity of 26.4 °/₀₀ was controlled without any difficulty, whereas with the drum brake the northern slope of the Thuringer-Wald with a total length of 12 km, an average gradient of 20 °/₀₀ with a 6 km of 25 °/₀₀ was the limit the brake gear could give. At the cost of heavy wear of the linings naturally, the Arlberg bank was run down in safety with the disc brake on one only of the three bogies.

The conclusions resulting from these tests and the results of other trials with disc brakes could not be made use of immediately because of the war. It was only very much later when the series construction of railcars could be resumed that drum brakes were given up and disc brakes alone were used. There are now in service 1 565 two axled vehicles and 279 four axled vehicles fitted with disc brakes or in all 4 246 pairs of wheels (motor vehicles, trailer vehicles with driving compartment, middle vehicles, ordinary trailers). Further vehicles with disc brakes are being designed and include a Diesel locomotive. Except for the Wegmann train, there are no passenger coaches equipped with disc brakes, although it is expected a certain number of suburban vehicles will be fitted.

Earlier, we called attention to the defects in the old brake linings and the perfecting of improved types. It can be stated without exaggeration that as the properties of the linings control the possibility of using brakes with artificial linings, the high efficiencies today obtained as well as the good results in service, must be attributed essentially to the very great progress made in the linings materials. Later, we will give some details of the evolution, the conditions to be fulfilled, the properties as well as the methods of selection and test.

Beforehand, however, we should stop to consider several questions of principle of importance when comparing the brake block type of brake and the disc brake, and also in relation to the stresses set up.

2. General properties of the types of brakes on railway vehicles.

2.1. *Brake block type of brake.*

The brake using brake blocks is very robust. The cast iron blocks are relatively cheap and can be obtained everywhere. The blocks in two parts are even standardised internationally so that they can be replaced readily even abroad. They stand up to the rough usage on railways and are not affected by atmospheric conditions. A brake block made red hot during braking can be used again when cooled down if not excessively worn.

To counter these good features, how-

(*) These numbers refer to the bibliography at the end of the article.

ever, the coefficient of friction of cast iron blocks is far from ideal in its application. One especially unfavourable feature is that it varies as a function of the speed of running [5], which in the usual application on passenger and goods trains limits the maximum usable braking force to a value such that there is no reason to fear the wheels being skidded at slow speeds [1]. At high speeds, the coefficient of friction, sure regulator, pressure transformer, and charging valves of the regime in use — involves complication of the layout as a whole, because owing to the relation between the coefficient of friction and the specific pressure of the block, the braking force has to be increased at high speeds in proportions greater than the acceleration by itself would require (about as 1 : 2 to 1 : 2.6).

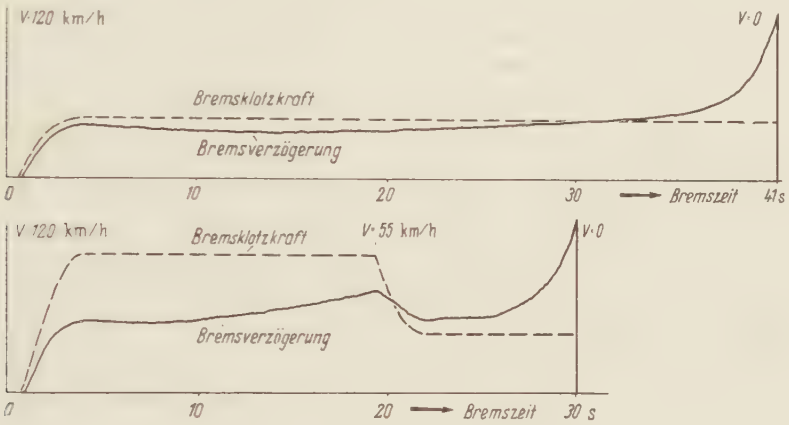

Fig. 1 *a* and *b*. — Variation in the effort at the brake block and in the deceleration with a brake using blocks as a function of the braking time during rapid braking from 120 km/h.

a) One stage brake in position P.
Effort at the block : 70-80 % of the axle load;

b) Powerful two stage brake in position R.
Effort at the block : above 55 km/h, 160-180 %; below 55 km/h, 70-80 %.

N. B. — Bremsverzögerung = deceleration, — Bremsklotzkraft = effort at the block. — Bremszeit = braking time.

then definitely lower, produces a braking of mediocre value only utilising imperfectly the available adhesion between the rail and the wheel (fig. 1 *a*).

Nevertheless, in order to obtain satisfactory braking with cast iron blocks at high speed on express trains of types S or R higher brake block pressures are used at the high speeds, which at lower speeds (below 50 km/h) are reduced to a value corresponding to this range of speeds by means of an automatic regulator (fig. 1 *b*). The equipment needed [7] — brake pres-

The coefficient of friction is not only a function, as we have just indicated, of the speed and of the specific surface pressure of the brake block, but also of the form of the blocks, of their hardness, and of the temperature. They do, however, present a degree of stable conditions seeing that under equal conditions, they behave almost exactly in the same way and largely independently of the material within the tolerances of composition and hardness laid down in the purchasing department specifications.

A serious drawback, however, is the wear [2] on the one hand which requires, owing to its extent, frequent renewals under high efforts and on the other, because of the quantity and nature of the dust produced which seriously soils the line, the installations and the vehicles, and reduces the electrical resistance of their insulation. Furthermore, the noise and vibration during braking are additional defects of the brake using brake blocks.

Although earlier on we described the brake block type of brake as being « robust », certain reserves as regards this attribute must be made relatively to the tyres. These are already highly stressed by the axle loads, the shrinkage allowance and the lamination effect of rolling on the rails. During braking, they have to withstand in addition conjointly with the blocks the work produced which can be very considerable [3]. The supplementary stressing results from the heat engendered during braking which can cause very high temperature peaks on the surface of the tyres and also raise the mean temperature of the latter.

The rise in mean tyre temperature involves — owing to the flow of heat producing between the tyre and the rim, a range of temperature increased by an accummulation of heat at the joint separating them — a reduction in the shrinkage allowances and deterioration in the fitting of the tyre.

At normal brake stops, even if these follow one another at frequent intervals, the mean tyre temperatures do not rise high enough to affect the shrinkage. This possibility is greater when descending long gradients; the working instructions to which we will return in § 3.2 should take care to ensure that certain limits are not exceeded. Moreover a loose tyre does not generally mean any danger, as it is held in position by a lip and Gibson ring, and also is not subject to stresses of high enough value to overcome the retaining forces and to cause the tyre to turn round. Usually as the temperature falls, the tyre becomes secure again.

The mean tyre temperatures in service are below the critical temperatures of the tyre steel so there is no reason to fear changes of texture.

It is quite a different matter as regards the surface temperature of the tyre. It has not been possible yet to measure precisely these temperatures, but the fact that when braking at high speeds there are dense showers of sparks between bright red and bright yellow, leads to the conclusion that at the surface of contact between block and tyre the temperatures reach 850 to 1 100° C. Now these temperatures are above the high points of transformation of the steel and modifications of grain texture are possible even though the duration of these temperatures is very short and only affect a very small part of the tyre surface. This situation is particularly dangerous as regards high tensile tyres, used for locomotive and railcar tyres, in which the stresses from high pressure and prolonged braking result in the formation of martensite and intercrystalline fissures extending to the surfaces which can be the beginning of fatigue fractures. It is therefore important to take very good care in selecting the quality of steel for tyres of heavy, high speed vehicles, and also to check these tyres in service for cracks. The high temperatures can also result in the metal of the brake blocks being welded to the tyres and this spoils the quality of the rolling surface.

During the development of the railcars for the fast services in the Ruhr (ET 30), fitted with brake blocks and the working of which involves very high braking forces, the above experiences led to the fitting of a two pressure brake with high deceleration on the light carrying bogies only, whilst the heavy motor bogies were braked with a single stage P brake.

2.2. *Brake with composition linings.*

The linings of drum and disc brakes are, owing to their internal structure, complicated products owing a great deal to the technique of plastics. Their properties

depend not only upon their composition; the method of fabrication also exerts a considerable influence; both must be laid down and carefully respected during manufacture.

High quality linings — the only ones which will satisfy the particularly heavy exigencies of railway vehicles — must have a coefficient of friction largely independent of the speed, of the specific pressure, of the temperature and of atmospheric conditions. Such properties can also be obtained by means of suitable mixtures and fabrication methods (see chapter 4). However, temperatures of more than 400° C cannot be supported for an extended period, even in the case of the best products, because carbonisation of the bonding materials. The linings will continue to brake effectively at high temperatures — possibly even with an increased coefficient of friction — but will then wear very quickly, their properties becoming considerably modified, and they can no longer be used after cooling down.

With normal stresses. the wear of the brake linings is very slight. For equal volume and performance, it is only 1/8th to 1/12th of that of cast iron blocks, but as the volume that is affected by wear is appreciably less than in the case of brake blocks (for a disc brake about 20 to 40 % according to the equipment of the vehicle), this advantage is generally not fully made use of. In comparable cases, the life of disc brake linings up to the time they have to be replaced, compared with that of brake blocks is in the ratio of approximately 1 : 3 to 1 : 6. Quite apart from the definitely lower amounts of the products of wear, it must also be considered that the very fine dust formed essentially by carbonised lining material has less harmful effects than the abrasion of the blocks of metal brakes.

The very uniform value of the coefficient of friction over the whole range of speeds is very well adapted to the analogous behaviour of the coefficient of friction between wheel and rail which can thus be profited from to more or less the same extent at all speeds (fig. 2). Consequently, brakes with composition linings assure good braking at high speeds; the regulation of the braking effort as a function of the speed is no longer necessary as it is with the high speed brake with blocks. The higher coefficient of friction than with block brakes moreover makes it possible to use lower efforts and consequently to have smaller brake cylinders and lighter rigging.

The brake with composition lining, even with a constant pressure in the cylinder, gives uniform deceleration as well as very « smooth » braking, and is in addition very quiet. These properties often give the impression that the brake is not sufficiently effective. It is often objected in particular that the absence of any increase in the coefficient of friction immediately prior to stopping, to which the block brake has accustomed us, makes it more difficult to brake to a stop accurately. In this respect, it can be pointed out in reply that the driver must become accustomed to the particular characteristics of his vehicle both during running and during braking, and if it is fitted with a brake with composition lining, he must use a somewhat different braking technique to that he used with vehicles fitted with block brakes. Obviously, this may cause the drivers a certain amount of trouble, especially when there are only a few vehicles out of a large stock fitted with brakes with composition linings, so that the men only rarely have to drive them. For example 42 engine crews at the present time share in the driving of the Wegmann train on the « Blauer Enzian » (Blue Gentian) service on the Hamburg-Munich run, and each of them only drive this train which is the only train with disc brakes at the present time and hauled by a locomotive with block brakes once every 24 days. Previously, when steam locomotives were used, the number of engine crews concerned was as many as 84. Consequently, on various occasions to begin with, there were certain incidents in connection with the braking, due to mistakes of manoeuvre, but they were not capital ones and were due to the special way it had to be used. Other Administra-

tions have also found that trial vehicles fitted with brakes with composition linings used by themselves when there was a large stock of vehicles, without taking any special steps or giving any special instructions for their use, did not give the expected advantages. But when the number of vehicles with brakes with composition linings increased, the position became more favourable and in general the difficulties disappeared as the staff became more familiar with this new type of brake. Stops can be made just as accurately as with service so as not to damage the linings of the brake discs, makes it necessary to take special precautions as regards the dimensions of the whole installations, and in particular in designing the discs. (This remark applies even more to drum brakes on account of their poor thermic behaviour, but as they are no longer being used on new stock, we will not dwell on this point.) Brake discs must be dimensioned as a function of the performance expected of them, but here they have the advantage that, unlike tyres, they only have to withstand

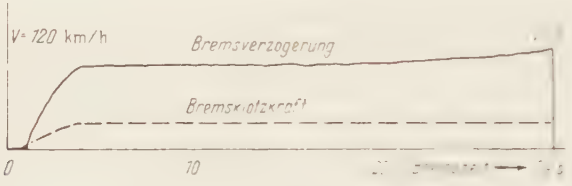

Fig. 2. — Variation of the braking effort and deceleration with a disc brake as a function of the braking time during rapid braking from 120 km/h. Effort related to the periphery of the wheel: 30 to 35 % of the axle load.

block brakes, even the putting into position of units occupied by passengers for coupling up the Scharfenberg couplings, which is frequently necessary in the case of fast railcar and small railcar services can be done without any shock. It must not be forgotten that these brakings to a stop are service brakings for which the whole of the braking effort is not applied, but on the contrary the deceleration is regulated as required by means of the pressure in the brake cylinder; moreover, even with block brakes care must be taken not to stop with a sudden shock, which must be avoided by releasing the brake at the right moment. Consequently, the possibility of regulating the pressure in the brake cylinder is more important as regards accurate braking than the variation of the coefficient of friction at low speeds.

The need to avoid prolonged temperatures above approximately 400° C during the work of braking, and apart from the limitations imposed by the space available, their design can be based entirely by this work.

Brake discs must have on the one hand a certain accumulation capacity in order to absorb the peak temperatures, but on the other hand they must also have good cooling properties. Their design has already been dealt with in numerous articles [2], [4] and we will not dwell thereon but merely report that until recently discs were always made of cast steel, but recently interest has been shown in cast iron discs once more owing to the greater resistance of cast iron to heat and the more favourable coefficient of friction. In simple cases (small units), discs have also been made from simple steel plate. The braking powers that can be absorbed by the different types, in prolonged service, before critical temperatures are reached for the brake lin-

ings, can be ascertained from trials; they can be calculated by means of the « coefficient of cooling » [1], [2], [4].

Brake discs at first sight appear to involve an increase in the axle weight. But this is compensated, compared with block brakes, by the reduced weight of the brake levers and linings, as well as that of all the rigging, especially compared with the double block arrangement which is essential to obtain high braking powers. Often disc brakes thus make it possible to simplify and facilitate the design of vehicles or bogies [2].

The simplicity of the arrangement of the brake rigging in the case of disc brakes makes it possible to house it on the bogie. The arrangement adopted to begin with, with which each brake application lever was applied by a double cylinder [1] was given up in more recent designs, seeing that the numerous cylinders required had a tendency to lead to leakages. Usually at the present time there is one brake cylinder per axle [2].

In the first designs of disc brakes (Wegmann train, panoramic railcar), two pairs of application levers per disc were used to limit the specific pressure on the linings. This measure was found to be unnecessary because the linings can be stressed without inconvenience up to specific pressures of 6 kg/cm². For some time therefore a single pair of application levers per disc has been used, which has the advantage of improving the cooling of the disc owing to the increase in the area of the surface that is not covered.

The play between the lining and the disc not being modified by the deflection of the springs, it is possible, with disc brakes, to use very small amounts of play, of 1 to 2 mm. In this way, it is possible to have short piston strokes and the minimum consumption of air. This reduced play is also desirable because it prevents the penetration of foreign matters between the disc and the linings, especially snow and ice. To make it possible to observe such small play, automatic devices are used to regulate the linings, or recently, automatic devices for regulating the rigging incorporated in the brake cylinder have been used [2].

3. Special properties of the disc brake.

The question which arises at the present time is to decide what conclusions can be drawn from the differences between the properties of the block brake and the brake with composition linings, if the latter can be fitted into the normal braking services or whether it requires special treatment. It is necessary to take into account the fact that the design of ordinary vehicles, the type of compressed air brake, as well as the braking operations as a whole, together with the regulations governing this, have been elaborated entirely as a function of the characteristics of the block brake.

3.1. *Action and stopping distances with disc brakes.*

The particular characteristic of the coefficient of friction of the brake lining predestines the disc brake for use above all on fast vehicles; at high speeds it allows of shorter stopping distances than a block brake having analogous variation of the brake cylinder pressure, i.e. a brake of type P.

In figure 3, a comparison has been made of stopping distances on the level for different rakes and motor coaches, empty, fitted with block brakes and disc brakes. It must however be stressed that rakes of 60 axles, the braking of which is influenced by the time of propagation and other pneumatic phenomena, are at somewhat of a disadvantage in comparison with shorter rail motor coach rakes, and on the other hand, we should not confine ourselves to distinguishing in these comparisons between the different kinds of brake material — cast iron or composition lining — but also take into account the design of the brake as a whole : deceleration, time taken to refill the brake cylinder, arrangement of the rigging, form of shoe, etc. These latter influences can, under certain conditions, appreciably modify the properties of the materials. For example, the stopping dist-

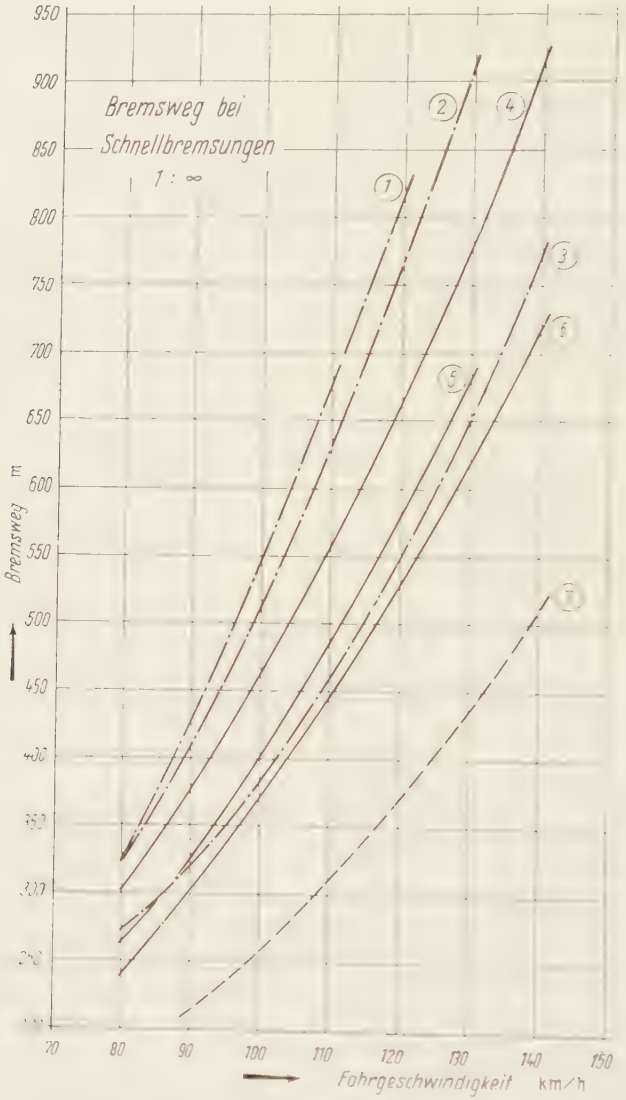

Fig. 3. — Stopping distances with rapid braking on level lines.

Vehicles fitted with block brakes :

(1) 60 axle passenger train, old coaches with Kp brakes and single brake blocks, type P brake.
(2) 60 axle passenger train, modern coaches with KE brakes and double brake blocks, type P brake.
(3) Id. type R brake.

Vehicles fitted with disc brakes :

(4) 12 axle Diesel rail motor coach rake . . . . . VT 08
(5) 8 axle A.C. rail motor coach rake . . . . . ET 25
(6) 28 axle Diesel rail motor coach rake . . . . . TEE
(7) Idem with electro-magnetic brake acting on rails.

N. B. — Bremsweg bei Schnellbremsungen = stopping distance with rapid braking. — Fahrgeschwindigkeit = running speed.

ances of trains fitted with P block brakes differ considerably according to whether it is a question of coaches fitted with old types of brakes with single blocks, or coaches equipped with modern brakes with double blocks (curves 1 and 2). Curve 2 more or less coincides with the values for motor units and rail motor coach rakes of current design, such as for example the A.C. rail motor coaches ET 13, ET 26 and ET 30. Curve 3 shows the braking action that it is possible to obtain with a high power block brake by regulating the effort at the blocks as a function of the speed.

The stopping distances for vehicles fitted with disc brakes of the usual design lie in general within the space between curves 4 and 5. Curve 4 relates to the VT 08 Diesel rake but also applies to other similar railcars; VT 12, ET 30, articulated rail motor coach rakes, etc. Curve 5 gives the stopping distances for an ET 25 rake after replacing the drum brakes by disc brakes. But under particularly favourable conditions, braking may be even better, as is shown by curve 6 for the TEE 7 unit rake, whose stopping distances are slightly shorter than those of the passenger train fitted with the high power KE-GPR block brake with regulation of the pressure in the brake cylinder in two stages (curve 3).

To obtain a still better brake action in the case of fast braking, an electro-magnetic brake acting on the rails can be added to the brakes acting on the wheels. This has, it is true, a variation of the coefficient of friction similar to that of a block brake with an increase in the deceleration at the end of the braking. But seeing that the coefficient of friction of the brake linings remains constant, the electro-magnetic brake is much less unpleasant in conjunction with disc brakes than in conjunction with block brakes (fig. 4). If it is desired to obtain the same stopping distances as with brakes acting on the wheels

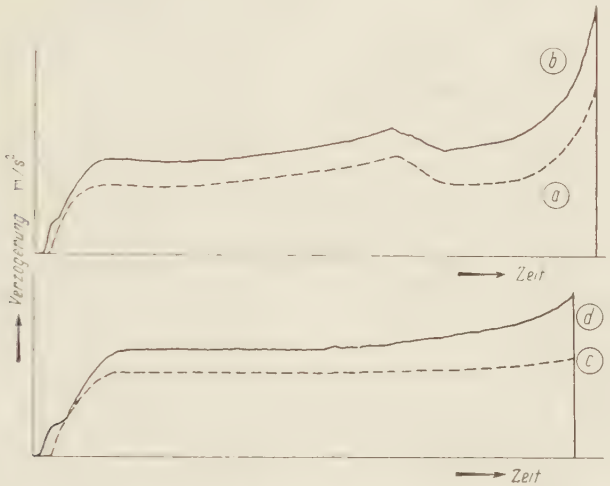

Fig. 4. — Variation in deceleration during rapid braking with the application of electromagnetic brakes on rails, block brakes and disc brakes.

a) Powerful block brake, only;
b) Id. with electromagnetic brake acting on rails;
c) Disc brake, only;
d) Id. with electromagnetic brake acting on rails.

N. B. — Zeit = time. — Verzögerung = deceleration.

at 120 km/h, the initial speed, when an electro magnetic brake acting on the rails is added, can be increased by 15 to 40 km/h according to the total magnetic force of attraction installed (30 to 80 % of the weight of the vehicle). On the TEE rake, for example, the addition of a magnetic force of attraction of 46 % of the weight of the rake gives in the case of rapid braking at 144 km/h, the same stopping distance as with the disc brake by itself at 120 km/h (fig. 3, curve 7).

Although in the range of low speeds, the stopping distances of vehicles equipped with disc brakes are often longer than those of vehicles fitted with block brakes with fast braking, the former are also used with good results on vehicles with low maximum speeds. This is the case, in particular, in circumstances where special importance is attached to other properties of the brake with composition lining mentioned above : smooth and noiseless braking, reduced wear, suppression of metallic dust, and simplicity of design.

The slightly lower braking action at low speeds can be made good easily enough in the case of ordinary braking in service, where in any case only part of the available braking power is used, by the use of an appropriate service technique. For example, mention may be made of what occurs on the Hamburg urban railway where 44 half-rakes fitted with block brakes and 28 half-rakes fitted with disc brakes run in no matter what order and are coupled together. In the case of fast braking of empty rakes on lines on the level, with the compressed air brake of the type in use, the stopping distances in the case of the disc brakes are longer below 60 km/h and shorter above this speed, than those of the block brakes (as can be seen from fig 5 from the average deceleration curves in the case of rapid braking). By means of greater deceleration with the disc brakes, it is possible to get similar stopping distances in both cases below approximately 50 km/h, but most of the vehicles show the results given in figure 5. In spite of these differences, the average braking decelerations obtained in the case of braking during service, in which first of all the rheostatic brakes are applied, then, below 35 km/h only, the compressed air brakes, with disc and block brakes, within the same limits of dispersion of results, the upper limit still being sufficiently below the maximum deceleration obtainable. The great area of the field of dispersal can be explained by the fact that the peaks have been reached during regular working with different conditions of occupation, different permanent way conditions and with different drivers. By coupling together half-rakes fitted with different types of brakes, the same deceleration values have been obtained. To obtain these decelerations, in the case of rakes fitted with block brakes on the average a maximum pressure of the brake cylinder of 1.03 kg/cm² has been used, and with disc brakes, a pressure of 1.7 kg/cm² i.e. 33 and 55 % respectively of the value which can be obtained in braking in service. The rakes have always been braked to a standstill in this way at the prescribed places with a precision of less than 1 m.

3.2. *Possibility of use in service and stresses.*

To appreciate the stresses to which brakes can be subjected in service, it is necessary briefly to examine the traffic regulations. These are based on the general principle that, apart from restrictions imposed for other reasons, a train should run at such a speed that it can be braked to a stop in the distance of the warning signal on the steepest down gradient.

To be able to work to and check this regulation in a simple fashion, the properties of vehicles as regards braking are determined according to an international comparative system, expressed by what is called the brake-weight [6]. The quotient of the brake-weight by the weight of the vehicle is called the braking percentage : for a given type of brake this forms a practical measurement of the action of the brake. It is therefore possible to lay down the minimum braking percentage which a train must have in order to be able to run at a given speed over a line having

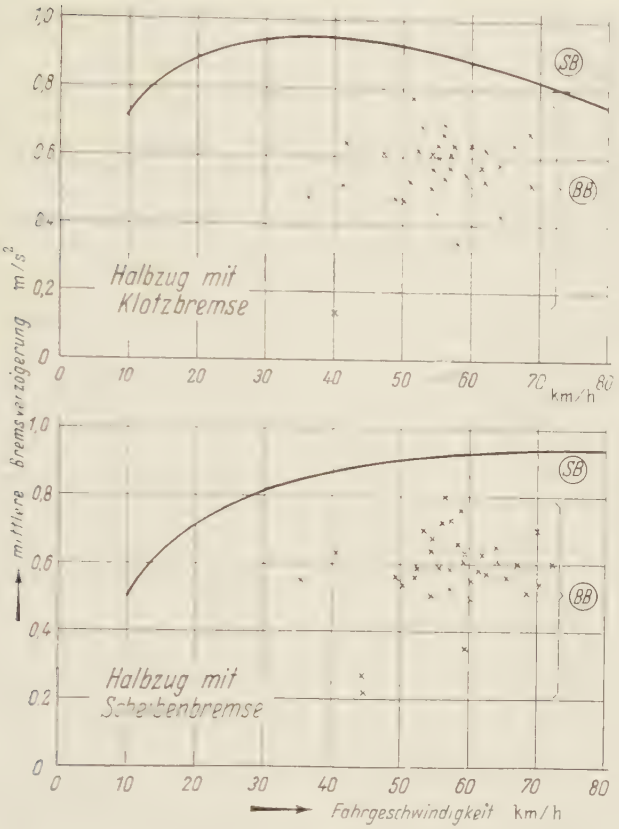

Fig. 5. — Average decelerations of trains on the « Hamburg S. Bahn » fitted with block brakes and with disc brakes.

SB : Variation in rapid braking with compressed air brake, empty half-rake 1 : ∞.

BB : Zone of dispersion during service braking with normal user with rheostatic and compressed air brakes for different degrees of occupation and different permanent way conditions.

N. B. — Halbzug mit Klotzbremse = half-rake with block brake. — Halbzug mit Scheibenbremse = half-rake with disc brake. — Fahrgeschwindigkeit = running speed. — Mittlere Bremsverzögerung = average deceleration.

a given profile. These minimum percentages are given in the corresponding tables of the traffic regulations; they are an important basic factor in drawing up the timetables and making up the trains. These tables are drawn up for stopping distances of 400, 700, and 1 000 m and subdivided according to the types of brake I and II (quick acting brake and slow acting brake).

Within the framework of this system, it is possible and moreover necessary from the operating point of view, to add to a train whose braked vehicles give a high braking percentage, a number of wagons without brakes or wagons with low braking power within the permitted limits for the percentage laid down for the train as a whole in the working timetable. Goods trains

are generally made up in this way; but this can also be done in the case of passenger trains. In the case of such trains, simple braking to a stop on lines on the level or on a slight down gradient does not give rise to any fears of excessive stresses, seeing that a lower speed also means a lower braking power. But is is quite another matter on steep gradients when the train has to be heavily braked in order to respect the speeds laid down.

This can be made clear by an example :

Let us suppose we have a passenger train made up of coaches fitted with P brakes, which, locomotive and load included, has a braking percentage of 96 %. According to the braking tables, for 700 m type I brake, it can run at a maximum speed of 100 km/h on gradients of 5 °/₀₀. On gradients of 20 °/₀₀ , where the maximum speed is reduced to 65 km/h on account of the curve, only 58 % braking is required. It is therefore possible to add to this train vehicles with less efficient brakes until this value is reached; the power to be absorbed by the well braked vehicles will then be 2/3rd higher than if the train ran down this gradient with its 96 % braking. If on the section with the down gradient the distance of the advance signal was 1 000 m, which only requires a braking percentage of 46 % at 65 km/h, the power might be more than doubled. The braking power of the strongly braked axles would increase still more if the train has not only a braking power of 96 %, but was made up with some coaches fitted with high power brakes capable of giving a percentage of 130 to 170 %.

These conditions, however, have already been taken into consideration in the braking tables. The minimum braking percentages required on steep gradients are higher than needed to respect the safe stopping distances alone, and are moreover calculated in such a way that the quantities of heat produced under existing conditions of the profile can be absorbed by the brake blocks in the usual case, without any fear of damage to the tyres. Such considerations only apply however on the one hand to standard wheels (diameter approx. 1 000 mm) and on the other hand to G and P brakes, which in general give a percentage of up to 110 and on light vehicles up to 120 (related to the tare). With fast brakes, on the contrary, if these minimum braking percentages are calculated according to the high brake-weights of the position S (R), the power may become so great on steep gradients that even after a short time the difference in temperature between the tyre and the rim at which the tyre is loosened is reached. On steep gradients therefore it is necessary for all the vehicles to be more or less equally braked. Isolated vehicles with higher braking powers, for example coaches equipped with rapid brakes, must therefore be used with the type of brake corresponding to the majority of the others; they must therefore be put in the position P. According to the special regulations concerning steep gradients, it often happens that the full value of the brake-weights of position P is not taken into account in calculating the braking percentages.

This however occasions difficulties in the case of vehicles fitted with disc brakes owing to the fact that in their action and owing to their brake-weight, they are equivalent to high speed brakes, but from the point of view of working they are P brakes and do not include in the device for changing from one regime to the other, a second brake position for passenger train operation. As a result, they have only one braking percentage — usually a very high one — and consequently when running with minimum braking percentage, they will be very highly stressed. In the case of vehicles and rail motor coaches, which always run with vehicles of the same nature, it does not appear that any cases of running with minimum percentages will occur; even if the brake of one of the coaches was damaged, the minima would not yet be reached in general. With small railcars such a case might occur if they were hauling goods wagons. As it is a question here of regular services, it is easy to take suitable steps, and tables have been prepared showing the loads hauled and pos-

sible speeds taking into account the braking powers admissible with disc brakes.

The problem becomes more difficult when it is wished to equip passenger coaches with brakes with composition linings. For operating reasons, such coaches must be able to run everywhere; they must therefore also be able to run with minimum braking values. This is one of the reasons — together with insufficiently perfected designs — which led to the failure of the above mentioned trials of fitting express coaches with drum brakes.

In the case of a coach fitted with disc brakes, with an axle load of 7.5 t, which with a properly calculated brake may attain about 140 % of braking power, it would be necessary to absorb 37 HP per axle on a gradient of 25 °/₀₀ at 65 km/h, the braking power being taken as uniformly distributed. With a minimum braking of 48 %, which according to the braking tables would be adequate on such a gradient at 60 km/h, the power at the braked axles would rise to 108 HP. This is a value which it is already hard to deal with and which makes it necessary to count upon very high temperatures during long down gradient runs.

It would however be erroneous and lead to poor user of the properties of disc brakes to brake more lightly as a matter of course or make calculations on the basis of a lower braking percentage in the case of vehicles fitted with such brakes in order to take into account the above considerations. A regime changing device allowing of reduced braking in such cases does not solve the problem either, as it would uselessly complicate the pneumatic portion of the disc brake equipment. Such measures are, however, in no way necessary, and the protection of the brake against excessive stresses can be assured by suitable working rules, for example by not calculating the minimum braking percentage for down gradients according to the maximum brake-weight, as is already done in special cases with block brakes.

Since coaches equipped with disc brakes do not imply the inscription of a second lower brake-weight, it is necessary to indicate a coefficient of reduction by means of which the brake-weight is multiplied in cases where it is necessary to calculate the minimum braking percentages for sections with steep gradients (16 °/₀₀ and above). As in general in the case of block brakes, the brake-weights in position P are equal to approximately 0.7 times the value S, it would be advisable to use this coefficient. We then get instead of 140 % as initially, about 100 % only, and the power per axle at the minimum braking percentages will only be 76 HP which can easily be allowed. With a TEE rake which develops 156 % when all its brakes are working at full strength, trial runs were made on a line in the Black Forest at minimum braking percentages; the temperatures arising were sufficiently below the critical temperature.

Another difficulty occurs with vehicles equipped with disc brakes as regards testing the brakes and checking the linings. Testing the brakes is a very important safety measure for the operating [1]; when making a complete brake test it is necessary to check the application of the brake blocks of all the vehicles. With block brakes, the operation is quite simple as a rule — at least to some extent — as they can be seen from outside and reached by the examiner's long handled hammer. With disc brakes it is much more difficult, especially in the case of the disc between the wheels. In addition the play of the scissor-levers is so small that it is practically impossible to see if they are acting. The problem has therefore been solved by means of indicator devices [2] mounted outside the body of the coach and inserted into the brake cylinder conduit. According to the condition of the brake, these show a notice « brake free » or » brake engaged ». This simply indicates however whether there is any compressed air in the brake cylinder. In general, it is taken for granted that in this case the scissor-levers are working, but naturally it is possible for mechanical faults to occur which would prevent them from moving. In the case of vehicles and rail motor coach trains which are overhauled

at regular intervals over an inspection pit it would appear — particularly in view of the small wear of the brake linings — that it is quite positive for the indicator device to show the true position of the brake scissor-levers. In the case of coaches used in a pooling system, which are rarely checked over an inspection pit, it is necessary to be able to check the brake scissor-levers directly. The fitting of a control rod between the brake scissor-levers and a mechanical indicator device would not appear advisable owing to the great multiplication made necessary on account of the very slight movement of the scissor-levers. A device has also been suggested with rods fastened to the scissor-levers and ending outside the body, which would allow the condition of the scissor-levers to be checked by tapping. But it must not be forgotten that with pooling, a very large number of men would have to be instructed in the way the brakes were to be tested on such vehicles. It cannot be taken for granted that the men will completely understand the working of such devices and consequently it is better to adopt some arrangement whereby the scissor-levers are at least approximately in the same positions as the blocks in the case of other types of brakes. In this case, in spite of the increased weight, it is better to give the preference to the type in which the brake discs are placed on each side of the wheel centres where the outer levers are visible and accessible.

With railcars and other vehicles which are always used on the same services, it is a relatively simple matter to stock replacement linings, especially as there are only two sizes of linings, one for the small railcars and trailers, and the other for all the other vehicles. If there is pooling, greater difficulties will arise. Although the useful life of linings is considerable, it may become necessary to replace one anywhere, and the possibility of using the vehicles will certainly be limited as a consequence.

An argument that is often brought up in comparing block brakes with disc brakes, is the tendency to form flats, and it is often admitted that this occurs more frequently with the latter. It is certain that brake blocks on account of the friction they set up clean the running surface of the tyres. In the case of wheels that are not braked on the running surface, a spot of grease picked up when running through a dirty station or shed may remain on the tyre for a considerable time and contribute to decreasing the adhesion. To avoid this with certain foreign designs of disc brakes special additional « cleaning blocks » have been provided; these were first used on the D.B. on the motor bogies of the ET 30011 A.C. rail motor coach, where they also serve as antislip brakes. The block brake has the further advantage that in the long run slight flats become worn out and therefore less perceptible.

In judging the tendency to form flats, it must be remembered that owing to the small coefficient of adhesion between the wheel and the rail, the braking conditions of railway vehicles are as a general rule very unfavourable — much more unfavourable than in the case of road vehicles — and to obtain decelerations that can really be used in service, in calculating the brakes it is necessary to go almost as far as the lower limit of adhesion. The degree of utilisation of the coefficient of adhesion depends on the value of the deceleration desired and it is quite obvious that in the one case as in the other — block brakes or disc brakes — shorter stopping distances will increase the tendency to form flats. The vehicles corresponding to the curves 4 and 5 (fig. 3) which are fitted with disc brakes, might be for this reason alone more prone to form flats than the vehicles fitted with block brakes like those in curves 1 and 2, without it being necessary to admit that the conditions of adhesion are in principle worse. Unfortunately, exact comparative measurements of the adhesion are not as yet available for wheels braked by blocks and by disc brakes.

The regular rolling of the wheels during the operation of braking can be upset by a whole series of influences, some of which are incalculable. These are, on the one hand, local reductions of the coefficient of adhesion as well as the removal of the load from the following axles caused by the

deceleration, and on the other hand increases in the coefficient of friction and increases in the braking efforts beyond the calculated values due to mistakes in application. Should there be a combination of several of these circumstances, it would be quite impossible to avoid the formation of flats completely. However this combination depends very much upon chance, as can be seen from the fact that the number of flats is very small compared with the number of axles in service, and it is rare for all the axles of a train to be affected; in general only isolated axles are, usually the rear axles.

It is therefore very difficult to demonstrate that for an equal calculation of the user of the coefficient of adhesion the probability of forming flats is the greater or the smaller in the case of disc brakes than in the case of block brakes, seeing that there are no directly comparable vehicles. On the Hamburg urban railway (S. Bahn), the number of flats is always higher on rakes fitted with block brakes, but with these again the number is higher than the general average. In this case the circumstances are quite particular : a great number of brakings, frequently unfavourable atmospheric conditions, simultaneous use of electric and compressed air brakes, constructional design, frequent changes of staff at the terminal stations, etc., so that it is not possible to generalise purely and simply the facts noted on the Hamburg Railway.

It is therefore not yet possible to give any reliable answer to the question of the greater or lesser tendency to form flats, but it would appear that this is no longer of capital importance, since there are devices which function perfectly thanks to which the axles of costly vehicles can be protected against the consequences of skidded wheels (anti-skidding regulator).

4. Choice and inspection of brake linings.

4.1. *Stresses to which linings on railway and road vehicles are subjected.*

The quality of brake linings is of capital importance, as we have already shown when dealing with their behaviour on railway vehicles. The conditions they must fulfil are very severe, and definitely more exacting than those governing the usual types of brake linings for road vehicles.

Table 1 gives interesting data concerning the stress conditions. It shows in juxtaposition certain specific values characteristic of the stresses of linings, taken from the technical characteristics and operating conditions of well known rail motor coach rakes, fitted with brakes with composition linings, and heavy road vehicles. The axle loads shown in column 4 include the proportions of the useful loads of the vehicles when occupied or with maximum loads. The influence of the revolving masses is taken into account in the determination of the work done by the brake by means of the factors 1.1 for the motor axles of ET 30, and 1.05 for its carrying axles, as well as for the axles of the other vehicles. In addition, it is supposed that the braking conditions are regulated in such a way that the braking devices of each axle each absorb the brake stresses due to the static axle loads and revolving masses. In calculating the average braking powers in the case of braking to a stop from V_{max}, we started with the decelerations to be expected in the case of powerful braking (fast braking for railway vehicles) of fully occupied or loaded vehicles, without the intervention of the electromagnetic brakes acting on the rails nor the utilisation of the braking effect of the engine.

It will be seen that the average speeds of sliding between the lining and the corresponding rubbing surface often appreciably exceed, on the brakes of railway vehicles, the usual speeds on motor vehicles (column 10). At the maximum speeds allowed in the case of railway vehicles, they vary between 13.7 and 25.7 m/sec whereas they are only 7.3 to 9.4 m/sec on the brakes of the road vehicles considered. The directives of the Federal Ministry of Transport on approved automobile components [17] lays down in chapter 29 (brake linings) maximum speeds of sliding of 12 m/sec; so that it will be appreciated that

TABLE I. — Synoptic table showing the stressing of brake linings on different railway and road vehicles.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Vehicle axle	Maximum running speed	Type of brake	Axle load when full or fully loaded	Number of discs or drums per axle	Lining surface per disc or drum	Weight of vehicle per cm² of lining surface	Diameter of wheel tyres	Useful diameter of disc or drum	Average speed of slide at V_{max}	When braking to a stop from V_{max}: Braking work per axle	Average deceleration V/t	Average braking power per axle	Braking work per cm² of lining surface	Average braking power per cm² of lining surface
	V_{max}	—	G	z	F	$\frac{G}{Z \cdot F}$	D	d	v	A	b_t	$N = \frac{A \cdot 3.6 \cdot b_t}{75 \cdot V_{max}}$	$\frac{A}{z \cdot F}$	$\frac{N}{z \cdot F}$
	km/h	—	kg	—	cm²	kg/cm²	mm	mm	m/s	mkg	m/s²	HP	mkg/cm²	HP/cm²
VT 11⁵ (TEE)	140	Disc brake												
Motor axle . . .			16 000	2	800	10.0	950	620	25.4	1 300 000	1.0	446	812	0.28
Carrying axle VT			8 300	2	800	5.2	900	494	21.4	672 000		231	420	0.145
Carrying axle VM			6 500	1	800	8.1	900	494	21.4	525 000		181	661	0.226
VT 08⁵	140	»												
Motor axle . . .			18 900	2	800	11.8	940	620	25.7	1 520 000	0.7	365	950	0.228
Carrying axle VT			11 800	1	800	14.8	900	494	21.4	950 000		228	1 190	0.285
Carrying axle VM			9 800	1	800	12.3	900	494	21.4	792 000		191	990	0.239
VT 95⁹	90	»												
Motor axle . . .			10 200	1	800	12.7	900	494	13.7	341 000	1.2	217	416	0.271
Carrying axle . .			10 200	1	800	12.7	900	494	13.7	341 000		217	416	0.271
ET 30 011	120	»												
Motor axle . . .			21 000	2	800	13.1	1 100	770	23.3	1 320 000	0.8	422	825	0.264
Carrying axle ET			13 700	2	800	8.6	950	504	17.7	811 000		260	508	0.163
Carrying axle EM			11 000	2	800	6.9	950	504	17.7	653 000		209	408	0.131
ET 25 108	120	»												
Motor axle . . .			16 600	2	800	10.4	950	530	18.6	980 000	0.8	314	615	0.197
Carrying axle . .			11 700	2	800	7.3	950	530	18.6	692 000		222	435	0.139
ET 25 003	120	Drum brake with outside												
Motor axle . . .			15 900	2	640	12.4	950	680	23.9	940 000	0.75	282	735	0.22
Carrying axle . .			11 400	2	680	8.4	950	600	21.1	675 000		203	500	0.15
Motorcar KMO133A	73	Drum brake with												
Front			4 500	2	656	3.4	1 042	400	7.8	98 000	3.0	192	74.6	0.146
Rear			8 300	2	1 070	3.9	1 042	440	8.55	182 000		357	85.5	0.167
Motorcar MKH 2	80	»												
Front			4 400	2	680	3.2	1 042	440	9.4	116 000	3.0	209	85.5	0.154
Rear			8 600	2	955	4.5	1 042	440	9.4	227 000		409	120.0	0.214
Lorry Bü 8000	61.5	»												
Front			5 500	2	1 200	2.3	1 126	480	7.3	86 000	3.0	201	35.9	0.168

the examples taken from the domain of brakes for road vehicles for this comparison are well within the practical values as regards the speed of slide between the linings and corresponding friction surface. On the other hand on the railway vehicles, at the periphery of the discs, at the maximum admissible speeds of 140 km/h, there are maximum speeds of slide between the friction surfaces of the order of 30 m/sec and over.

The brakes of motor vehicles generally work with higher specific pressures of the lining (up to 12 kg/cm², compared with 6 at the maximum for the brakes of railway vehicles). In addition, on the heavy brakes of motor vehicles, linings are used that have a higher coefficient of friction. Hence the result, which may appear surprising at first sight, that in spite of the higher speeds of slide between the frictional surfaces in the case of railway vehicle brakes, the average braking powers per square centimetre of the surface of the lining when braking to a stop from V_{max} at the average decelerations indicated :

0.131 — 0.280 HP/cm² on railway vehicles, and

0.146 — 0.240 HP/cm² on motor vehicles,

are of the same order of value (column 15). In appreciating these more or less equal values of the specific power, which have been determined for this table from the average work of braking and deceleration, but which in the end are none other than the products of the values of p, v and μ in each case, it must not be forgotten that the influence of these factors upon the behaviour of the linings from the point of view of the coefficient of friction and of wear must certainly not be considered as identical, and probably the speed of slide is of predominating importance.

The weights of the vehicle per square centimetre of the surface of the lining, shown in column 7, allows of certain conclusions being drawn as regards the stresses of the linings on down gradients [15]. They lie between 5.2 and 14.8 kg/cm² in the case of railway vehicles and between 2.3 and 4.5 kg/cm² in the case of motor vehicles. On down gradients, all other things being equal, the brakes of railway vehicles transform into heat two to three times as much work per unit of surface of the linings. This does not necessarily mean that the stressing of the material is higher proportionately, as this stress is a function to a large extent of the temperatures of the lining and the body of the brake. The value of these temperatures on down gradients, all other conditions being equal, is also a function of the cooling conditions — proportion of the friction surface with linings to the unlined surface, total surface of the brake disc itself, access to it by the wind set up by running, etc. In this connection, brakes with composition linings on railway vehicles, especially those in the form of discs, are advantageous. But in addition to this fact, which undoubtdely diminishes the stressing of the material of the brake linings of railway vehicles, it must be remembered that in practice when road motor vehicles are running downhill, a very large proportion of the gravity component is absorbed by the engines, which relieves the brake linings to a much greater extent than happens in the case of railway vehicles even under the most favourable cooling conditions.

To utilise the traction engines when running downhill or braking to a stop railway motor coach sets presupposes mechanical changes of gear when they are driven by thermal engines, or in the case of electric traction, larger dimensioning of the traction motors to correspond to the longer time they will be functioning as well as the additional devices such as braking resistances, brake regulators, fans, etc. Mechanical changing of gear is only applicable however in the case of low powers (small railcars). In the case of heavy rakes with thermal engines, to ask the engines which are already heavily stressed by their own job of driving the train to play a part in the braking cannot be considered a happy solution. The oversize engines — compared with traction requirements — as well as the other arrangements needed for electric rail motor coach rakes, gives

rise to relatively high costs; in addition, there is sometimes the difficulty of lack of space. The engines of rail motor coach rakes can therefore only play a part in the braking in a few special cases, both in the case of running down long gradients or braking to a stop. Such special cases occur, for example, on hilly sections or in the case of suburban traffic. In addition, it must not be forgotten that on railway motor coach rakes, the participation of the engine in the braking relieves the brake linings much less than it does in the case of road motor vehicles, as conditions are completely different (proportion of motor axles to total number of axles, low value of adhesion of the wheel on the rail).

The braking effort per square centimetre of surface of the lining in braking to a stop from V_{max} (column 14) is particularly striking. The figures reached by railway vehicles, 408 to 1 190 mkg/cm² are nearly ten times greater than those for the brakes of motor vehicles. These violent stresses may possibly be repeated several times at very short intervals. When the ET 30 was used on the fast services in the Ruhr, the Hamm (Westph.) to Dusseldorf Central run or the return run (about 108 km) includes 25 brakings to stop, 18 of which, according to the present working timetables, are from 120 km/h. The average distance between stops is 4.35 km. To take into account projected services, it is even required that the braking equipment on this rail motor coach set makes it possible for it to run over the section in question with the stops spaced at an average distance of 2.5 km at a running speed of 120 km/h, with average acceleration and deceleration of 0.7 m/sec² and a half-minute stop at each station. Let us say at once that trials carried out in service with the ET 30011 rake fitted with disc brakes have already proved that this programme is realisable without difficulty, and there is completely acceptable wear of the linings with the qualities of brake linings specified by the D.B.

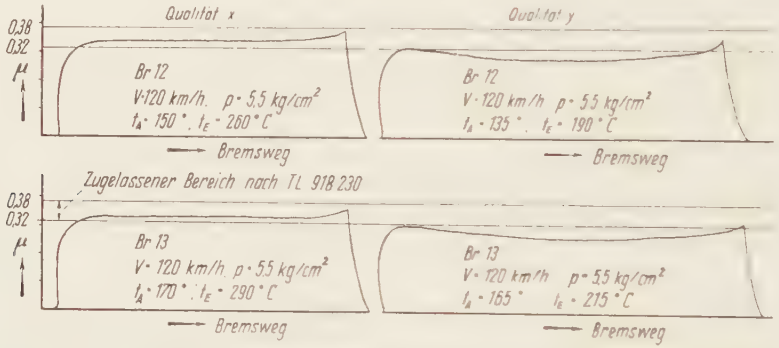

Fig. 6. — Variation in the coefficient of friction during successive brakings on the test bench testing complete linings for disc brakes.

Left : quality conforming to conditions.

Right : quality which does not conform with conditions.

N. B. — Qualität = quality. — Bremsweg = stopping distance. — Zugelassener Bereich nach... = authorised limits according...

As we have already stated elsewhere in the present article, certain ordinary coaches, which run in complete trains, are fitted with disc brakes. It is proposed to fit these to a small number of other coaches. The axle loads are 7 to 10 t; consequently with the brake dimensions proposed, the stresses of the linings correspond more or less to the lower figures given for railway vehicles in Table I. It must not be forgotten, however, as was stated above, that when mixed with vehicles equipped with less powerful

brakes, definitely higher stresses may occur in the linings.

The special features of railway operating mean that certain other considerations apply in choosing the brake linings, which need not be taken into account to the same extent in the brake linings of road vehicles. The low coefficient of adhesion between the rail and the wheel [1] as well as the difficulty of braking individually the different units of a rake according to the condition of the rail and the occupation or load, involve very close tolerances for the coefficient of friction, as we shall explain in greater detail in § 4.3. For example, the coefficient of friction of the lining when run in must only vary by ± 20 % at the specific pressures of full application of the brakes, as well as at all the speeds of slide and temperatures occurring in service, and the effects of humidity. On the other hand, the « Directives for testing vehicle components » [17] issued as a result of § 22 of the « Regulations for authorising vehicles to run on the roads », states in clause 29 :

— for the linings of motor vehicles of class GH, average coefficients of friction of 0.35 to 0.45 with a total average dispersion of 50 %;

— for the linings of motor vehicles of class GN, the same average coefficients of friction, with a total average dispersion of 35 %.

Nor must it be forgotten that in the case of brake linings for railway vehicles, the indicated scale of dispersion covers the instantaneous coefficient of friction (see fig. 7) in each case, whereas in the case of linings for motor vehicles, it is merely question of the « average total dispersion », i.e. the maximum difference between the average coefficients of friction found during various tests with various stresses related to the average coefficient of friction of the whole series of tests.

The condition of the greatest possible insensitivity to humidity is of particular importance in the case of linings for railway vehicles, where the brakes are not protected by any covering, so that the linings are, as it is easy to see, much more exposed to atmospheric influences than those of brakes with internal scissor-levers used on motor vehicles. It must also be mentioned that the above coefficients of friction required for the linings of disc have to be obtained from friction on cast steel as well as on cast iron.

4.2. *Historical review of the evolution of brake linings for railway vehicles.*

Twenty-five years ago, when the first railway vehicles fitted with brakes with composition linings were built, the only materials available for the brakes were the friction materials used for the brakes of motor vehicles and cranes and developed for use on such vehicles. These were based on the use of asbestos to provide the needed strength as well as to form the friction material, and artificial resin as the impregnation or bonding material. These were used in the form of mesh or woven and then compressed in a press. Such linings sometimes were satisfactory on the level when braking did not occur at too close intervals, or on short and not too steep down gradients. When brake applications at high speed followed one another in rapid succession, or when running down long, steep gradients, the impregnating or bonding matters were driven out and ended by burning up. The consequences were as follows : a lot of smoke and unpleasant smell, considerable variations in the coefficient of friction, very heavy wear, and finally, in the worst cases, the destruction of the linings. When affected by humidity, to which the exposed linings of railway vehicles are often much exposed during the winter when it is snowing, the coefficient of friction of linings of asbestos mesh with long fibres fell to 25 % and less of the values obtained when they were dry under similar braking conditions [2], [8].

Work undertaken to improve the frictional properties of such linings when damp or severely heated, gave interesting results to some extent, but were soon abandoned, on the one hand because owing to political events which had taken place in the mean-

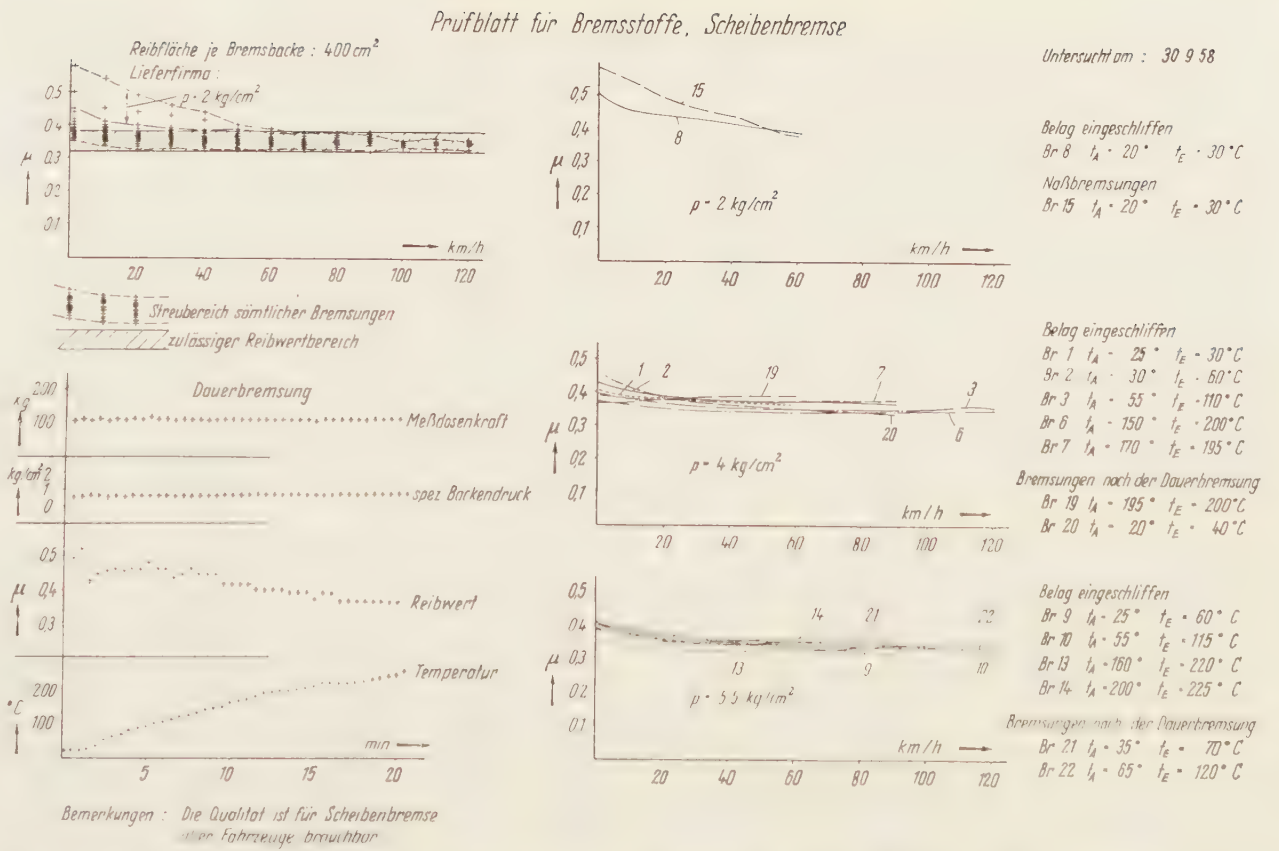
Prüfblatt für Bremsstoffe, Scheibenbremse
Reibfläche je Bremsbacke : 400 cm²
Lieferfirma :
p = 2 kg/cm²
km/h
Streubereich sämtlicher Bremsungen
zulässiger Reibwertbereich
Dauerbremsung
Meßdosenkraft
spez. Backendruck
Reibwert
Temperatur
min
Bemerkungen : Die Qualität ist für Scheibenbremse
Untersucht am : 30 9 58
Belag eingeschliffen
Br 8 tA = 20° tE = 30°C
Naßbremsungen
Br 15 tA = 20° tE = 30°C
p = 2 kg/cm²
p = 4 kg/cm²
Belag eingeschliffen
Br 1 tA = 25° tE = 30°C
Br 2 tA = 30° tE = 60°C
Br 3 tA = 55° tE = 110°C
Br 6 tA = 150° tE = 200°C
Br 7 tA = 170° tE = 195°C
Bremsungen nach der Dauerbremsung
Br 19 tA = 195° tE = 200°C
Br 20 tA = 20° tE = 40°C
Belag eingeschliffen
Br 9 tA = 25° tE = 60°C
Br 10 tA = 55° tE = 115°C
Br 13 tA = 160° tE = 220°C
Br 14 tA = 200° tE = 225°C
Bremsungen nach der Dauerbremsung
Br 21 tA = 35° tE = 70°C
Br 22 tA = 65° tE = 120°C

Fig. 7. — Overall characteristics of coefficient of friction of lining for disc brake conforming with conditions after trial on test bench for complete linings.

N. B. — Prüfblatt... Scheibenbremse = test notes for brake material, disc brake. — Reibfläche je Bremsbacke = friction surface per scissor-lever. — Lieferfirma = supplier. — Streubereich... Bremsungen = limits of dispersion for all the brakings. — Zulässiger Reibwertbereich = admissible limits of coefficient of friction. — Dauerbremsung = prolonged braking. — Messdosenkraft = effort at measuring box. — Spez. Backendruck = specific pressure of scissor-levers. — Reibwert = coefficient of friction. — Untersucht am = tests carried out on the... — Belag eingeschliffen = run in lining. — Nassbremsungen = damp brakings. — Bremsungen nach der Dauerbremsung = brakings after prolonged braking. — Bemerkungen... = observations : the quality is suitable for disc brakes for all vehicles.

while asbestos was no longer available for this purpose, and on the other hand, because marked progress towards making friction materials which were not affected by heat or damp had been made.

Rudolf Oswald, the owner of a firm making brake linings at Ohorn (Saxony) devoted himself in 1934 to the problem of finding a new fibrous and heat resisting material for brake linings to replace asbestos [9], [10]. It was discovered that aluminium or soft steel fibres of about 0.03 mm diameter were very suitable for this purpose. Metal wool with the addition of a certain quantity of powdered material could be made into compressed brake linings by using as bonding agent either artificial resin or synthetic rubber (Buna) stable at high temperatures. Such linings were practically insensitive to damp or showed very little wear. Owing to the good thermal conductivity of the material, there was no accumulation of heat and consequently no excessive heating of the frictional surfaces; the coefficient of friction remained practically invariable, even at temperature above 300° C. The synthetic rubber made very stable as regards heat by suitable treatment gave rise to less offensive smells than most of the artificial resins formerly used for brake linings. The first friction materials based on metal wool were manufactured by Oswald in the second half of 1934; at the same time he applied for patents for the principle. The perfecting of this type of lining had practically been completed by the end of 1937. During the trials mentioned at the beginning of this article with a Hamburg type fast railcar fitted with new bogies with disc brakes on the west gradient of the Arlberg in 1939, these materials were used and gave the best results. The steel wool and « Buna » linings were passed for disc and drum brakes and were generally used on the railway vehicles of the former Reichsbahn from 1938 till the end of the war.

In addition to the material for linings based on steel wool and Buna, patented by Oswald, which complied with the requirements for brake linings for railway vehicles and the necessities of the position regarding raw materials, until the end of the war another type of lining was available using native products designed at about the same time. This consisted essentially of asbestos dust and other mineral powders bonded together with « Buna ». This was very little affected by damp; in addition the coefficient of friction remained constant as a rule during average braking stresses. This product was used during trials of a fast Hamburg type railcar with bogies fitted with disc brakes on the west gradient of the Arlberg; from the point of view of resistance to heat, it was found however to be definitely inferior to the material based on steel wool and « Buna ».

For the sake of completeness, we should also mention that before the war relatively satisfactory results had been obtained with brake materials based on waste asbestos bonded by means of artificial resin and « Buna » [8]. However trials of this material had to be abandoned as the asbestos waste was no longer available for this purpose. Trials with a view to replacing asbestos fibres by peat fibres with a metallic thread or other national products failed completely [8]. The evolution was finally completely interrupted by the events of the war.

After the war, things only progressed slowly. The Saxon firms which formerly supplied the linings needed for railway vehicles with drum or disc brakes were out of action. The work of the factories in Western Germany had to contend with serious difficulties to begin with owing to the shortage or poor quality of the raw materials available. Owing to the constantly varying quality of the essential raw materials imported, the frictional properties, the most important, of the linings varied from one consignment to another, so that on several occasions the results of much painstaking work had to be taken out of manufacture. Finally, the situation became even more difficult owing to the fact that it was necessary first of all to make linings for existing vehicles, fitted with drum brakes, with which thermic conditions and other difficulties that had to

be overcome, led to particularly serious problems as regards the resistance to heat of the brake materials.

Finally, little by little, suitable brake materials were perfected both for disc brakes and drum brakes. Since « Buna » has once more been procurable of unvarying quality and in sufficient quantity, brake linings have been designed for railway vehicles which largely meet requirements as regards resistance to heat and damp, the wear of the linings and the effects upon the corresponding friction material.

The following figures will give some idea of the difficulties which had to be overcome since the end of the war until the technique of brake linings reached the above briefly summarised level :

From 1947 to mid 1958, the Brake Testing Department of the Bundesbahn carried out composition tests on 309 friction materials for drum or disc brakes on railway vehicles, put out by 16 different firms. As a result of these tests, 19 materials from 5 firms were recognised as being usable and accepted. Some of the friction materials had to be taken off the list owing to a decline in their quality. When this article was written, there were 8 materials which met the requisite conditions, two of which were suitable for drum and disc brakes.

4.3. *Tests of brake linings for railway vehicles.*

In § 4.1, we drew attention to the great stresses to which brake linings on railway vehicles are subjected in service. To allow of the perfecting or selecting of suitable linings, and to keep a constant check upon the quality of deliveries, it was necessary to get out a suitable test method, adapted to the special conditions of railway operating.

This method comprises :

detailed technical specifications, fixing the dimensions as well as the frictional and other properties of the brake linings;

suitable test arrangements, and

a programme of tests designed to reproduce the conditions of stress occurring when railway vehicles are braked.

4.31. *Technical specifications.*

When the first railway vehicles were fitted with brakes with composition linings — as we said above these were drum brakes — the friction materials already used by the motor industry and in the construction of cranes were used. However, in view of the diversity of conditions under which they had to function, it soon became necessary to establish special principles applying to the supply of brake linings for railway vehicles as regards the dimensions, value of the coefficient of friction at different application pressures, speed of slide and temperatures, as well as in damp weather. These principles were improved upon as greater experience was obtained, and were adapted on several occasions to comply with the progress made in the construction of brakes and in the manufacture of the linings. When the situation became stabilised again after the second world war, they were made concrete in the « Technical Delivery Conditions for linings for drum and disc brakes on railway vehicles » (TL 918230). The edition in force at the present time is that of July 1951 with certain supplements.

The delivery conditions first of all lay down the procedure of acceptance and supply, give an idea of the existing dimensions and contain indications about the conditions of stress. The specific pressures are as high as 4 kg/cm^2 in the case of drum brakes and 6 kg/cm^2 in the case of disc brakes; the maximum speeds of slide are 33 m/sec; in addition allowance must be made for temperatures of as high as 450° C.

The stress conditions are the basis for the acceptance and supply tests for class II quality linings, which can be used on all vehicles. In the case of class I quality, linings intended for vehicles having a maximum speed of 90 km/h, the tests are somewhat less severe as regards the speed of slide and the temperature.

However, the value of the coefficient of friction must in every case lie between 0.32

and 0.38, both for drum brakes and for disc brakes. The variation in the coefficient of friction must as fas as possible be independent of the pressure of application, the speed of slide and the temperature. However, it would not be grounds for rejection if the coefficient of friction of linings for disc brakes exceeds the upper limit for specific pressures on the linings of 2 kg/cm² and below, which do not occur when the whole braking effort is applied. In the same way, for speeds of slide below 3 m/sec at the end of braking, an increase in the coefficient of friction up to 0.42 is allowed. If the lining is wet, the coefficient of friction may vary by not more than 15 % compared with the corresponding value of the coefficient of friction when it is dry. The same applies to the period of running in; here again the differences compared with the corresponding values for the run in condition of the lining must not exceed ± 15 %.

The acceptance and supply tests provide for braking to a stop up to the total pressure of the lining and until the speeds of slide corresponding to the maximum speeds of the vehicles to be fitted are reached, as well as prolonged braking at average speeds for periods of up to 20 min. For fuller details see further on the paragraph « Test programme ». The linings must stand up to these braking forces without suffering damage, smoking or catching fire, as well as without loss of the bonding material. The wear must not exceed 2 cm²/HP/h in the case of linings for drum brakes and 1 cm²/HP/h in the case of linings for disc brakes. On the other hand, in view of the running in of new linings, the wear of the linings must not be too small. The surfaces of friction in contact must not be damaged by the linings, and in particular there must not be any grooving.

Amongst the conditions governing delivery in the case of the general mechanical properties of the linings, mention may be made once more of the fact that the fabrics and the other bonding materials and additions must be uniformly distributed throughout the whole of the lining and there must not be any undue concentrations nor blebs. When rivetted to the scissor-levers, the linings must not break nor crack. They must not readily absorb water.

To determine whether these conditions have been observed, during the delivery and reception tests on trial lots, longitudinal and transversal cuts are made which are carefully examined; in addition the resistance to rivetting and the absorption of water in 24 h are determined. As regards resistance to rivetting, it is laid down that during the test with the device invented by the Brake Testing Department of the Bundesbahn, the bases of the rivets must stand up to at least two blows from a mass of 500 g falling from a height of 450 mm in the case of linings for drum brakes and a height of 350 mm in the case of linings for disc brakes. There are no set figures as regards the absorption of water in 24 h: this test, as well as the determination of the hardness and specific weight are intended above all to make it possible to compare the value of the different deliveries of a given quality of friction material, as well as with the reception tests for this quality.

The delivery conditions also include clauses dealing with manufacture, the dimensional tolerances to be respected, marking, delivery, and possibly replacements.

4.32. *Test arrangements.*

Amongst the properties of brake linings indicated in the delivery conditions, the observance of which must be proved by suitable tests, the variation in the friction at different pressures, speeds of slide and temperatures is of special importance. It must be stated here that — whathever test method is used — it is only possible to determine the behaviour of the pair as a whole, as the value and variation of the coefficient of friction depends not only on the material of which the lining is made, but also in every case, that of the disc or drum and the nature of their frictional surfaces.

To determine the frictional properties,

different methods can be used [11], [12], [13], [14], [16], according to whether it is a question of measuring the practical or physical coefficient of friction, whether average values are all that is needed or whether it is desired to know in detail the value of the friction as a function of the time or the distance, as well as the precision required for the values obtained :

a) test on an ordinary vehicle with composition brake lining. In this way, it is possible to determine the average coefficients of friction from the average decelerations measured during the braking tests. If the deceleration diagrams are recorded during the tests, it is possible to deduce therefrom also the approximate variation of the coefficient of friction. In view of the multiple influences, which it is not always possible to appreciate singly, of the vehicle itself including the brake and its state of repair, as well as those of the permanent way, it is not possible to be too demanding as regards the precision and general value of the figures found in this way. This method is often used in testing brake linings for motor vehicles;

b) test with measuring coach. Here the braking efforts are measured by the intermediary of a Prony brake and a recorder. It is possible to register immediately by using an electric calculator the quotient of the tangential effort by the effort of application — in other words the coefficent of friction — in a continuous fashion as a function of the time or the distance. Braking to a stop or prolonged braking can be tested. As the braking efforts can be measured very precisely by means of a Prony brake, the figures obtained are obviously more trustworthy than those obtained from running tests with an ordinary motor unit. However, even with this method, a series of factors which have no relation at all with the frictional material affect the result, so that there is no possible hope of obtaining the exact physical characteristic values applicable to the material of the lining working in conjunction with the material against which it is rubbing. But the same brakes are always used — disc or drum — from the point of view of the stock, the dimensions and the execution, as well as with linings of the same dimensions and as, moreover, the test conditions can be kept largely uniform, the method gives practical and comparable values for the friction and the wear;

c) tests of complete linings on the test bench. In this test, the linings are studied in their full size on real brake discs or drums. Generally, it is possible to brake to a stop as well as carry out prolonged braking. To store up the energy to be destroyed in braking to a stop, suitable centrifugal masses are used. The polar moment of inertia of these masses may reach 206 kg/m/sec². The braking efforts are measured by means of a Prony brake and can be recorded.

As regards the precision and value of the values obtained on the test bench for complete linings, we can repeat once more what we already said in connection with tests with a measuring coach. The bench method has certain advantages over the measuring coach because it is possible to eliminate the influences of the running wind, varying ambiant temperatures, and that of the permanent way. In addition, the carrying out of tests on a fixed bench is certainly simpler and faster than making tests with the measuring coach on lines in ordinary operation. On the other hand, this latter method is of value when it is desired to study precisely the effects of the wind set up by the running, of the ambiant temperature and the permanent way;

d) tests of part linings on the test bench. Here small particles of the linings to be studied are rubbed against small scale models of discs or drums made of the same material as the original discs or drums. According to whether only braking to a stop or else prolonged braking or both types of tests are required, there are test benches for the work and for the power and for combinations of the two. The energy to be destroyed in braking to a stop is absorbed by revolving masses. The

Brake Testing Department of the Bundesbahn has a combined work and power test bench. To measure the braking efforts, there is a Prony brake : braking efforts can be recorded as a function of the time and the displacement.

Tests of the power of part linings are of particular interest. In this test, during the whole duration of the test, are maintained constant :

1) the force of application and the speed of rotation, or

2) the braking effort = force of application × coefficient of friction and the speed of rotation.

In addition, it is possible to work at a constant average temperature of the frictional surfaces. This result is obtained either, in the testing of the constant braking power — last case — by carrying on the test until equilibrium is established, or — in both cases — by cooling or heating the other frictional surface.

As the tests on part linings make use of small samples from linings, it can be admitted that if the pressure of application is kept uniform, the specific pressures of the lining are also uniform over the whole frictional surface. In the testing of the power of the part lining on the drum — where the speeds of slide over the whole frictional surface are also uniform — it is therefore possible to determine the physical characteristics of the friction material being studied, in conjunction with the material of the other frictional surface, as a function of the specific application pressure, the speed of slide, and the temperature of the frictional surfaces.

The Brake Testing Department of the Deutsche Bundesbahn, according to the problem before them and the destination of the test as well as the desired precision of values to be found, works according to one or other of the above methods. However, the acceptance and reception tests laid down in TL 918230 are — except for a few rare exceptions in the case of the reception tests — carried out on a test bench with complete linings.

Unlike the innumerable types and sizes of brakes for motor vehicles, there are only a small number of forms and sizes of brake discs and drums for railway vehicles. The linings of disc brakes are all practically identical in form and size; and there are only a few sizes of linings for drum brakes. The disc brake is completely free from the phenomena of self-tightening; with drum brakes with outer scissor-levers, their influence is very slight. Under these special conditions, work and power tests on the test bench with complete linings give values for the friction and wear which can be made use of straight away under actual operating conditions.

During the tests, the braking effort and the force of application are recorded in a continuous fashion as a function of the travel; by means of a manual contact it is possible to add reference marks relating to the speed or time. A counter set in action at the beginning of the braking makes it possible to count the revolutions on the test bench up to standstill. From the results it is possible to obtain the stopping distance. The average temperature of the brake disc or drum are measured on the surfaces in friction by means of thermo-couples the junction of which is buried in a sliding shoe, and readings taken from the indicator device. Finally, the braking times are determined by means of a chronometer.

The linings are tested on cast steel discs or drums, which are practically the only kind used on the railway vehicles of the D.B. In acceptance tests, the linings are also tested on a grey iron disc.

4.33. *Test programme.*

As we have seen in the relative paragraph, the « Technical Specifications for drum and disc brake linings for railway vehicles » TL 918230 only give very general information about the stresses to which the linings are subjected from the point of view of the length of braking, the specific pressure of the linings, the speed of slide, the temperature, etc., during the acceptance and reception tests, and about the limits

of the coefficient of friction and wear which must be respected. The study of the coefficient of friction, by means of certain test programmes is therefore an essential part of the Technical Specifications. These programmes have been laid down and perfected by the Brake Testing Department of the Bundesbahn after long years of experience. The order of succession of the different brakings is determined in each case in such a way that, on the one hand, the most adverse conditions which might occur in service are carefully studied without subjecting the linings to be tested to excessive conditions, and on the other hand, the test can be completed in one working day.

Table 2 indicates, as an example, the programme for testing the coefficient of friction for disc brake linings on the test bench for testing complete linings. After a few running in brakings — generally 8 brakings to a stop from 90 km/h with a specific pressure of 5.5 kg/cm² after which the linings must make about 70 % contact — brakings to a stop are made from 60, 90, 120, and in the case of linings intended for fast railcars from 140 km/h under different specific pressures and temperatures. The way the quality of the lining stands up to damp is shown by braking No. 15 at 60 km/h under a pressure of $p = 2$ kg/cm² with a cold disc. After two other brakings to a stop with linings which are drying out, a prolonged braking lasting 20 min is made with all the linings with a power of 35 HP at $V = 60$ km/h and in the case of linings for fast railcars, a second prolonged braking with a power of 75 HP at 70 km/h until the friction surfaces reach an average temperature of 450° C. Brakings to a stop at the pressure $p = 4$ kg/cm² at different speeds, after a short preliminary loosening of the scissor-levers, end the prolonged braking. Finally, after the disc and linings have cooled off, three more brakings to a stop are carried out with increasing stresses. The work of braking to be absorbed in each case by the linings during these brakings to a stop corresponds to loads of 8 t per wheel.

The recording of the braking efforts and the forces of application during all the brakings makes it possible, in spite of the relatively small number of brakings on the test programme, to get a very pertinent and decided idea of the friction characteristics of the linings tested.

Figure 6 shows two extracts from the strips of recorded graphs. In both cases, these were brakings to a stop Nos. 12 and 13 of the test programme for linings for disc brakes according to Table 2. The right hand example relates to a quality of lining which did not meet the conditions, whereas the left hand example is from the test of a satisfactory lining.

The most important results of the study of the coefficient of friction of the qualities of linings submitted for acceptance are recapitulated in the « Test notes for brake materials ». These give the limits of dispersion of the values of the coefficient of friction for all brakings to stop — including running in brakings as a function of the speed, in addition, the variation of the coefficient of friction and the temperature as a function of the time during which the braking or brakings lasted, and finally the variation of the coefficient of friction as a function of the speed for some characteristic brakings to a stop as specific pressures of application of 2, 4 and 5.5 kg/cm². The test notes in the case of linings corresponding to the technical specifications are an essential part of the acceptance dossier.

Figure 7 shows the results of tests of the coefficient of friction recently carried out on an excellent disc brake lining for railway vehicles now on the market, in the form of a test note of this kind. On the other hand, figure 8 shows the test notes for a disc brake lining adapted in 1953 from a lining for a motor vehicle which cannot be used on railway vehicles.

During the current reception tests of linings of approved quality, only the initial and final coefficients of friction are taken into account together with the lowest values reached during braking, taken from the graphs and reported during the reports

TABLE 2. — **Test programme for the disc brake linings of railway vehicles at test bench for complete linings (« Minden programme »).**

Braking	V km/h	p kg/cm²	Initial temperature (2) °C	Observations
a — x	90	5.5	20 - 100	Braking to a stop as required to bed-down in the brake linings until they are about 70% run in. Temperatures of the discs not exceeding 200 °C.
1	60	4.0	20	Braking to a stop, dry.
2	90	4.0	30	Braking to a stop with increasing initial temperatures.
3 (1)	120	4.0	60	
4	120	4.0	100	
5	120	4.0	140	
6 (1)	120	4.0	180	
7	90	4.0	200	
8	60	2.0	20	Braking to a stop after a pause to allow for cooling.
9	90	5.5	30	
10 (1)	120	5.5	70	Braking to a stop at increasing initial temperatures.
11	120	5.5	140	
12	120	5.5	180	
13 (1)	120	5.5	200	
14	90	5.5	220	
15	60	2.0	20	Braking to a stop, when damp, after a pause for cooling.
16	90	4.0	50	Braking to a stop without any further damping.
17	90	5.5	70	
18 a	60	—	—	Prolonged braking I, 35 HP for 20 minutes.
18 b	70	—	—	Prolonged braking II, 75 HP for 10 minutes, in addition solely in the case of material No. 562.30/31. Stopped when temperature of the disc reaches 450 °C.
19	60	4.0	—	Braking to a stop when hot, immediately after prolonged braking I or II, without preliminary stopping of test bench.
20	90	4.0	20	Braking to a stop after a pause for cooling.
21	90	5.5	50	Successive brakings to a stop.
22	120	5.5	80	

(1) For brake linings of material No. 562.30/31 (fast vehicles), brakings Nos. 3, 6, 10 and 13 are carried out at V = 140 km/h.

(2) The initial temperatures given to be taken as a guide.

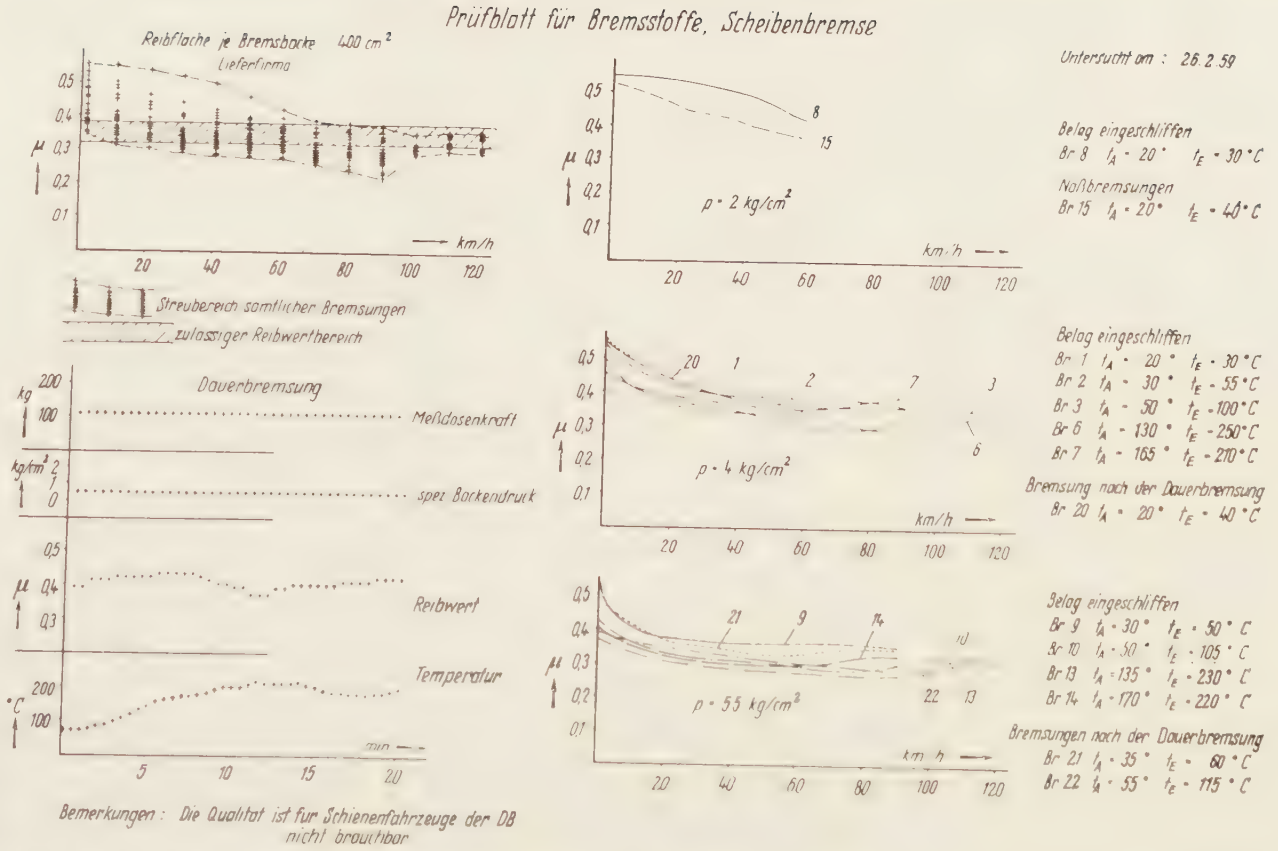
Prüfblatt für Bremsstoffe, Scheibenbremse
Reibfläche je Bremsbacke 400 cm²
Lieferfirma
μ
km/h
Streubereich sämtlicher Bremsungen
zulässiger Reibwertbereich
Dauerbremsung
kg
Meßdosenkraft
kg/cm²
spez. Backendruck
Reibwert
Temperatur
°C
min
Bemerkungen: Die Qualität ist für Schienenfahrzeuge der DB nicht brauchbar
p = 2 kg/cm²
p = 4 kg/cm²
p = 5,5 kg/cm²
Untersucht am: 26.2.59
Belag eingeschliffen
Br 8 tA = 20° tE = 30°C
Naßbremsungen
Br 15 tA = 20° tE = 40°C
Belag eingeschliffen
Br 1 tA = 20° tE = 30°C
Br 2 tA = 30° tE = 55°C
Br 3 tA = 50° tE = 100°C
Br 6 tA = 130° tE = 250°C
Br 7 tA = 165° tE = 270°C
Bremsung nach der Dauerbremsung
Br 20 tA = 20° tE = 40°C
Belag eingeschliffen
Br 9 tA = 30° tE = 50°C
Br 10 tA = 50° tE = 105°C
Br 13 tA = 135° tE = 230°C
Br 14 tA = 170° tE = 220°C
Bremsungen nach der Dauerbremsung
Br 21 tA = 35° tE = 80°C
Br 22 tA = 55° tE = 115°C

Fig. 8. — Overall characteristics of coefficient of friction of brake lining for disc brake not suitable for railway vehicles.

N. B. — Bemerkungen : Die Qualität... — observations : the quality is not suitable for D.B. railway vehicles.

of the test. In this case, these are sufficient for estimating the frictional characteristics.

To determine the wear, the lining is weighed before and after the tests of the coefficient of friction, and by taking the difference in weight, the speciic weights of the frictional materials, and the total braking work during the tests, the figures for the specific wear are obtained as $cm^3/HP.h$, which can be compared together. The linings for disc brakes now on the market during the whole test programme shown in Table 2 have a wear of about 0.25 to 0.5 $cm^3/HP.h$.

Summary.

The disc brake offers, as compared to the shoe, or block, brake which is provided with cast iron brake shoes and is usued for all railway vehicles which are not equipped with disc brakes, a number of important advantages owing to which it is fitted almost exclusively to the more up-to-date railcars, driving trailers, and vehicles with driving cabs as well as to the rail motor-trains of the German Federal Railways. If and when vehicles equipped with disc brakes are designed and put into operation it is necessary to make allowance for the special properties of these disc brakes especially when the vehicles concerned are intended to be used in all-round manner.

The operating efficiency of the disc brake depends, to a great extent, on the brake linings. As the working stress applied to these linings is far greater than in road motor-vehicles it is possible to use only high-grade qualities which have been specially developed for this purpose. The requirements the brake linings are expected to meet are contained in the « technical specifications ». Suitable makes are selected and permanently checked in compliance with a testing-programme which has been adapted, to a great extent, to the conditions existing in actual practice.

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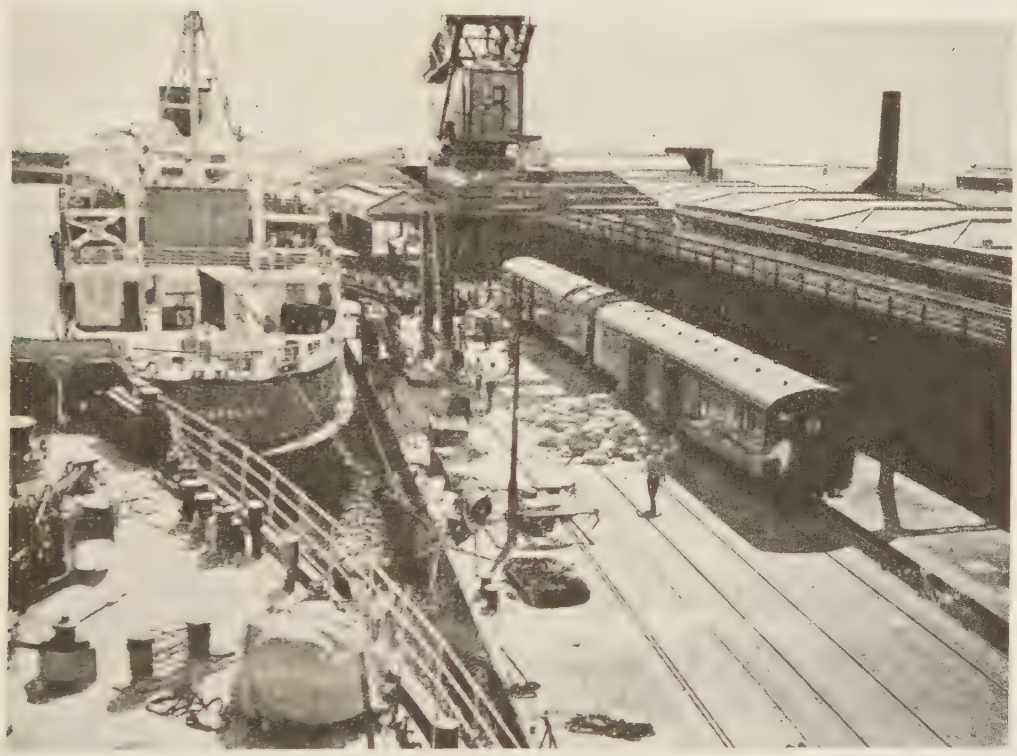
[621 .338 (42)]

On the Southern Region.

Direct current third rail traction.

Motor luggage vans with battery equipment.

(*Modern Transport*, October 1, 1960.)



Two motor luggage vans operating on the quay at Dover Marine on their batteries in conjunction with the Belgian boat train.

For historical reasons the Southern Region of British Railways employs direct current at 660 V in its electrified zone, transmitted to the trains by a third conductor rail, with running rail return. Under the modernisation plan this has been extended to the Kent Coast line serving Sheerness and the resorts of Margate and Ramsgate; it has already reached Dover via Faversham and Canterbury. Well in hand is the next phase in which the routes to Dover and Ramsgate via Ashford will be tackled and the Dover-Deal-Ramsgate route will be added. In the Battersea exhibition is one of the locomotives for this electrification, employed on boat trains such as

the *Night Ferry,* and also available for miscellaneous traffic and for passenger trains from other regions.

These machines, with motor generator equipment which prevents them being gapped on breaks in conductor rail, have already been described in our columns; less well known are the battery-powered self-propelled luggage vans which are added to multiple-unit boat trains for conveyance of passengers' luggage on to the Admiralty Pier at Dover and (eventually) alongside the boats at Folkestone. They thus need neither the third rail, with its attendant dangers to passengers on the quays, nor overhead wires which would interfere with crane operations.

For use with multiple-unit sets.

When, following electrification, it was decided that almost all boat trains should be made up of multiple-unit sets, a method of handling mail and registered baggage under Customs seal had to be devised. Ordinary vans attached to the multiple-unit trains were ruled out, even if fitted with air brakes, for two reasons : they would reduce the power to weight ratio of the trains, which would make them unable to keep up with other trains on the line, and, in the London direction, the train could not be driven from them. Motored bogie luggage vans were therefore being built with driving cabs at each end, two for the first phase of the electrification which came into service in 1959 and eight more for the second phase, when all boat trains except the *Golden Arrow* and the *Night Ferry* will be made up of multiple-unit sets.

Each van is the same length as the coaches of the multiple units, 64 ft. 6 in. over body ends and, apart from the two driving cabs and a small guard's compartment at one end, the whole of the floor space is given over to the conveyance of baggage, with a partition dividing the baggage compartment into two unequal sections. Three pairs of wide double doors are provided on each side, which are wide enough to take pallet trucks. Strengthened floors have been provided to allow trucks to manœuvre inside the vehicle. The general construction and the bogies are identical with those of the other electric coaches built for this scheme.

Electrical equipment.

The power and brake equipment, too, are the same as in the other coaches, but with important additions in each case. In order to avoid the use of shunting locomotives at the ports a 230 Ah traction battery is provided so that the vans can move under their own power on to the necessarily unelectrified quayside lines. This in turn opened the way to profitable use of the vans as light locomotives when not needed for boat train traffic, which is very peaky. In this role they are able to haul trains of up to about 100 tons and vacuum brake equipment has been provided to control the brakes on the trailing load. The brake on the van itself is controlled in the normal way from the air and electro-pneumatic driver's brake valve and a special valve then makes the train pipe vacuum vary in step with the brake cylinder pressure. Another newly developed valve assures the emergency features.

The traction battery is charged from the 200-V output of a motor generator set driven from the 750-V line; when it is required to provide traction power it is connected to the control gear and motors in place of the line supply by a contactor which is interlocked with the line switches to prevent both being closed at the same time. The van is therefore controlled in exactly the same way when powered by the battery as when powered from the line, but the performance is, of course, reduced. Selection of battery power is controlled by a push button in the cab, and reversion to line power may be obtained by operating a similar push button or by opening the master switch.

So long as the battery supply is selected, an indicator in each cab is illuminated and the collector shoes are pneumatically held clear of the conductor rail to allow exit from those unelectrified sidings which have no provision, such as a side ramp, for leading the shoes back on to the con-

ductor rail. A state-of-charge meter is also fitted to give the driver adequate warning of battery exhaustion. The compressor and exhauster are supplied from the traction battery, or from its charging supply when on the line, but the control gear and lighting are supplied from a 70-V source consisting of a generator driven by the same motor as the 200-V generator and a battery of 42 Ah capacity. Both batteries are of the lead-acid type, although all the control batteries on the multiple-unit sets are of the alkaline type.

Operation.

The first working of these M.L.V. cars started on June 15, 1959, on the Victoria-Dover Marine-Ostend boat trains, two round trips per day being made on that service. In this they were successful and at the beginning of 1960, with a view to making further tests under operating conditions, the 8.6 p.m. Cannon Street to Cannon Street parcels train was operated with one of the vans. The train runs down via the Dartford loop line, calling at the principal stations and shunting as necessary; on arrival at Dartford a van of mail, which has already been loaded and is standing in the dock in readiness, is attached and the train returns to London via the Bexleyheath line, again calling at prearranged stations. Station staff and travelling inspectors reported enthusiastically. So far as the actual M.L.V. is concerned, this is loaded and unloaded en route and gives satisfaction.

The E.E. 507 type motor, which develops a nominal 500 HP and is the same as that used on the Kent coast stock, stands up quite well to the work and is easily capable of hauling miscellaneous vehicles up to a tare of 100 tons. The fact that the van can operate away from the conductor rail for a period of 30 min by means of the storage batteries, is an essential and most useful feature.

Later, in order to obtain still further experience, a similar trip was scheduled from Holborn Viaduct to Wrotham, at which station the railway handles a heavy flow of parcels consisting of books printed at a nearby printing works; on the return journey to Holborn Viaduct the train called at Swanley for an extended period to load up plant traffic from the local nurseries. These are examples of uses for the M.L.V.s when Continental business is at a low level.

[656 .212 .4 (73)]

Skates replaced by automatic retarder.

(*Railway Age*, September 5, 1960.)

Fig. 1. — Retarders of the new mechanical type are placed at leaving ends of tracks in hump yards.

A cut of five cars, weighing a total of 337 tons, rolled down the hump of a gravity yard, through the master retarder and onto one of the body tracks. As it neared the far end of the 3 000-ft. track, and while moving at a speed of 7 m.p.h., the rims and flanges of the forward car were engaged by a device newly installed in the track. The cut of cars quickly slowed and stopped with the trailing truck of the second car and the lead truck of the third car in the retarder.

This movement was one of many tests made to determine the efficiency of an automatic, mechanical retarder developed for use in place of skates at the leaving ends of tracks in retarder yards. In another test the same cut of cars, moving at a speed of 9.1 m.p.h., was stopped with the trailing truck of the fourth car and the lead truck of the fifth car in the retarder.

The mechanical retarder under test was a prototype of a device developed by the Railroad Products Division of American Brake Shoe Company. As a result of experience with the prototype it was decided that worth-while benefits would be realized if the retarders were installed throughout the yard. Consequently, one of the retarders was installed in each of the body tracks at a point about 300 ft. from the leaving end.

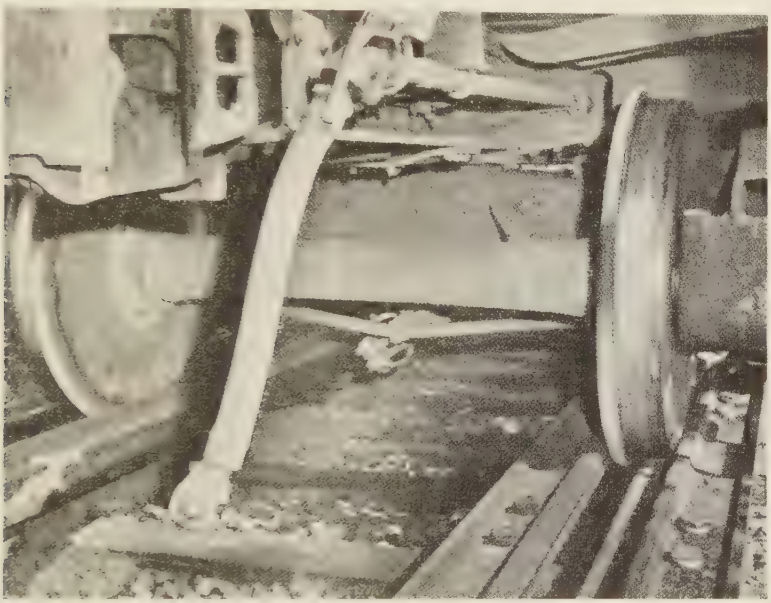


Fig. 2. — Braking effect is produced when retarder rails are caused by spring action to bear against rims and flanges of car wheels.

The retarder, generally supplied in 39-ft. lengths, consists of spring-loaded rails which apply retarding force simultaneously to both the rim and the flange of each pair of wheels. It is provided in the form of units that are installed opposite each other in the track. Each unit consists of two retarder rails mounted on opposite sides of the running rail and connected by nine spring assemblies.

Derailment threat eliminated.

When a car wheel enters a unit, the retarder rails are forced apart against spring pressure, providing a braking effect on the wheel. It is said that the retarding forces are applied to opposite faces of the wheel in such a way as to eliminate the possibility of derailment. No difficulty is said to be encountered in moving either the cars or the locomotive through the retarder when the track is being « pulled ».

In bringing a moving car to a stop, the action of the retarder, it is explained, has the effect of absorbing the kinetic energy generated by the car. It is claimed the device will absorb this energy at the rate of 9 000 ft.-lb. per foot of retarder length, or 350 000 ft-lb. for a 39-ft. retarder. Experience is said to have shown that a 39-ft. mechanical retarder will stop cars with average loads moving at 7.5 to 10 m.p.h.

In making the retarder installation mentioned above the railroad expected to realize a number of advantages. Similar installations on several other roads are producing estimated annual savings ranging from 30 to 60 % on the investment.

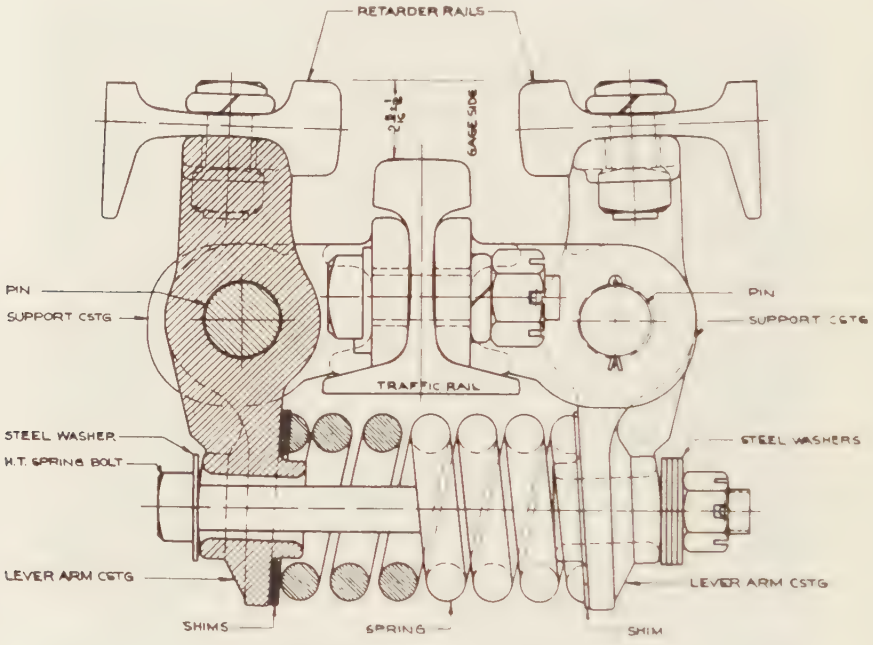


Fig. 3

(Block from *Railway Signaling Communications* for October 1960.)

These retarder installations are also expected to result in operating benefits. Since the skates had been placed at varying distances from the clearance points — almost in a straight line across the yard — the railroad figures the capacity of the yard has been increased by six or seven cars per track. Further, the number of cars per cut is no longer a factor, and trimming, when not entirely eliminated, is speeded up because it is not necessary to remove and replace skates and release hand brakes.

[656 .223 .2]

Operational research and the allocation of goods wagons,

by Dr.-Eng. Giuseppe Gullo.

(*Ingegneria Ferroviaria*, No. 7/8, July-August 1960.)

SUMMARY. — *The problem of the allocation of goods wagons may be considered as one particular case of one of the best known methods of operational research, that of linear programmation. Amongst the possible practical solutions, taking into account the working requirements of the allocators, that which appears to be the most suitable is the tabular method of advantages, which has already been dealt with in the review,* Ingegneria Ferroviaria, *which in addition to the necessary conditions of simplicity and rapidity, has the advantage of making it easy to take into account the varied conditions under which allocation must be carried out. An examination of the method leads to positive conclusions regarding its applicability, which is conditioned solely by the establishment of a suitable scale for the empty wagon costs. The allocator is thus in possession of precise working rules enabling him to obtain, in each case, minimum costs for the allocation of wagons. In addition, thanks to the preliminary study required of local shunting costs, the method proposed will bring out certain aspects of the railway installations.*

1. Indeterminate factors in transport and the problem of allocation of stock.

With all systems of transport, the characteristics which define the elementary transport are its consistency (volume, weight, number of units, etc...) and the run, which in principle, is the shortest kilometric run.

If these characteristics are known *a priori*, the transport is perfectly defined : under these conditions, the transporter responsible for carrying it out has only to arrange the necessary means along the predetermined route. This consideration always applies to railway transport of loaded stock, in which the criterion of the minimum run is sometimes modified in favour of runs which though longer, allow of lower transport costs.

But it does not apply to empty running, or rather to the movement of stock required for loading purposes. Passenger coaches as a general rule follow very complicated routings; they rarely have to make empty runs, and it is nearly always possible to make use of them to a greater or lesser extent. Even when this is not possible, the empty runs of coaches comply with the need for rapidly returning them to their previous departure station so that they can be used again.

However, in the case of goods transport, there is always a proportion of wagons which cannot be used where they are (1) so that they have to be sent elsewhere to be loaded again, which is what is known as *allocation of stock*.

What conditions have empty runs to meet to be determined ? Within the operating circumscription (regional or national) within which allocation must take place, there is always a group of m stations O_i (consigning) which have available empty wagons of the category required, and another group of n stations D_j (destination) which require these empty wagons.

(1) Tariff conditions are very much against any attempt to obtain complete utilisation of empties for loading goods. This is however taken into account in the concessions granting reduced tariffs.

The fundamental conditions of allocation are the following : in no matter what way it operates, each of the stations D_j must get empty wagons in a quantity which does not exceed its actual requirements; each of the stations O_i must forward wagons in a quantity not exceeding what it has actually available.

If x_{ij} ($\geqslant 0$) represents the quantity of wagons sent from O_i to D_j, the above conditions can be expressed analytically by the relations (of quantity) :

$$\sum_{1}^{n}{}_j \; x_{ij} \leqslant a_i \qquad (1)$$

$$\sum_{1}^{m} x_{ij} \leqslant b_i \qquad (2)$$

In the relations (1), there are inequalities when there is an excess of stock, i.e. when $\sum_{1}^{m}{}_i \; a_i > \sum_{1}^{n}{}_j \; b_j$; in the relations (2), there are inequalities when there is a shortage of stock, i.e. when $\sum_{1}^{m}{}_i \; a_i < \sum_{1}^{n}{}_j \; b_j$. But as we shall see, (1) and (2) can always be brought back to equations by introducing suitable new variables.

The above relations, even in the most simple cases, do not allow of determining the x_{ij} which are always greater in number than the equations; the problem is an indeterminate one (and usually extremely indeterminate).

To solve it, it is therefore necessary to introduce other conditions which in most cases are based on the idea of making the cost of running empty wagons as low as possible (but it is also possible in certain cases to require minimum allocation times).

2. The allocation of empty wagons on the Italian State Railways.

Within each Region, the allocation of empty wagons is arranged each day by one or several allocation zones. The Traffic Departments control the work of these zones, and in certain cases complete it.

A special Central Office of the Traffic Department assures, for the railway as a whole, the allocation of wagons with special characteristics, and deals above all with remedying any unbalance that may occur, especially at certain times of the year, between the stock available and the requirements of each Region, in correlation with traffic fluctuations.

Normally, therefore, there are local allocation circumscriptions and a national circumscription, within which the needs of the former are integrated.

The appropriate regulations (2) lay down in every detail the duties of the allocators. Clause 24 first of all specifies the criteria for the exact determination of the needs of the stations; it then goes on to say :

« The zones ... order those runs that are strictly necessary, taking care to reduce empty running to the minimum. »

Such is the working rule, obviously inspired by considerations of economy in transport, which should reduce the indetermination of the problem : the allocator must act in such a way that the total wagon-km of the empty wagons available for allocation is the minimum.

Using the previous notation, if d_{ij} is the distance between O_i (station having empties) and D_j (station needing empties), clause 24 states that the function :

$$C = \Sigma_{ij} \; d_{ij} \; x_{ij} \left(\begin{matrix} i = 1 \ldots\ldots m \\ j = 1 \ldots\ldots n \end{matrix} \right) \qquad (3)$$

must be minimum.

An examination of conditions (1) and (2) and the new condition (3) shows that the

(2) « Norme per il servizio ripartizione dei veicoli, copertoni, altri attrezzi e cartelli indicatori del perscorso delle carrosse » (*Rules for the allocation of vehicles, wagon sheets, other tackle and route plates of coaches*), 1952 edition.

allocator has to solve each day a special case of linear programmation, already dealt with on several occasions in the present Review : this is the « transport » or Hitchcock problem (3).

The allocator however is not always able to find an exact solution to the problem he has to solve daily (allocation is as old a necessity as the origins of railway transport, whilst the formulation of the Hitchcock problem is of recent date) : he takes care however to send the empty wagons to the stations closest to those with empties available, and avoids in any case crossings of stock, in other words the superposition of runs in opposite directions.

Thanks to these empirical criteria, and to the relative simplicity of the usual allocation plans, the practical solutions come very close to the theoretical solutions, and in fact often coincide with them.

The problem is however worth going into today to see whether, in the light of new operational theories, it is possible to find some form of practical solution to it, after having formulated it in a more precise fashion bringing it nearer to the economic realities of the cost of transport.

3. **The problem of transport costs.**

It must first of all be pointed out that proportionality between the cost of transport and the real distances, as postulated in clause 24 of the « Rules for the Allocation Department » is only approximate (and sometimes very approximate).

The cost of railway transport is made up of a great many factors (4), but as we shall see later on in the present investigation, *it will be necessary to consider only those connected with the characteristics of the run, which vary with the run.*

The factors in question include terms depending (owing to the shunting) upon the departure station, the intermediate stations at which the wagon changes trains, and terms depending linearly on the virtual distances and not the real distances; the most important of these latter is the consumption of fuel and electricity.

Other factors, such as the maintenance and repair of the rolling stock, are calculated according to the real distances.

It is known that the virtual distances differ from the real distances because they are a function of the layout and profile of the line, and because on the other hand they vary with the direction in which this line is run over.

To date, the allocators have not taken any of these circumstances into account. Nor have they been able to take into account the variation of the costs according to the system of traction used (electric, steam, diesel), nor of the fact that these costs may vary, with the same system of traction, from one section to another, and that they always vary (sometimes considerably) according to the direction in which the line is run over.

Another important factor, which so far has not been taken into account in investigations into favourable allocation, is the shunting at an intermediate station, when the wagon changes trains; the cost of such shunting, according to the data available, should never be overlooked.

Usually, in the case of the regional circumscription, allocation takes place by making use of the available capacity of the

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(3) Dr. Int. A. Russo-Frattasi : « Sulla programmazione « ottima » della distribuzione dei carri vuoti dai centri di concentramento ai centri utilizzatori » (*On the « optimum » programmation of the distribution of empty wagons from centres where they are concentrated to centres using them*), *Ingegneria Ferroviaria*, No. 12, Dec. 1957.

Dr. Ing. I. Adorisio : « Soluzione semplificata del problema di Hitchcock nella programmazione lineare » (*Simplified solution of the Hitchcock problem in linear programmation*), *Ingegneria Ferroviaria*, No. 10, Oct. 1958.

(3') J. de Lasala : The allocation of empty wagons by the application of operational research (*I.R.C.A. Bulletin* for June 1958).

(4) The factors which make up the total cost of transport number 25 according to the rules of the International Railway Union.

ordinary trains (especially the stopping pick-up trains) of which there are sufficient number for the average needs of each line.

It is therefore necessary to know the cost of the virtual tonne-kilometre *added* to the trains. This information can be supplied by the Accountancy Department of the F.S. for each section of line; the same department knows the marginal costs in the case of transport of empty wagons by special complete trains (empty rakes) of 50 or 45 wagons.

These two costs differ, because in the case of the special train, other factors also have to be taken into account.

Shunting when changing from one train to another at an intermediate station also has well known marginal costs : this is 182.75 Lire per wagon, taking into account merely the consumption of power, lubricants, and the maintenance of the locomotives.

As the average tare of the wagons is 9.87 t, the average cost of this shunting is therefore 19 Lire per ton.

All these figures are obtained from the traffic averages of the last financial year and are brought up to date every year.

With these costs, it would be possible to draw up a regional table, similar to the table of profiles, in which the cost of empty runs would replace the real distances. Such a table would however be far too big; it is preferable to recapitulate the costs for each of the sections forming the links in the regional lines, and then with the aid of these lists, draw up a scale covering the cost of the runs to and from the stations most often concerned in the matter of allocation, arranged in alphabetical order.

It is advisable that the scale includes numerous services, as the easiness of the allocator's work depends essentially on same.

Imagining that we have got out the necessary lists of the costs of the runs, we will now examine whether amongst the different solutions found for the Hitchcock problem, there are any which, for greater simplicity and rapidity, can be reduced to a small number of easy which the allocator will be able to make good use of.

In this way the problem of allocation might obtain a better solution than that now adopted in practice, which is in substance, *the approximate solution of a problem which in its turn has been stated according to the approximate consideration of the proportionality of the costs to the real distances.*

Before we continue, however, we want to make sure that even with the new more accurate formulation, the problem of allocation can still be considered as a transport or Hitchcock problem, and between what limits this applies.

This assimilation is exact whenever in the function « cost » :

$$C = \Sigma_{ij}\, c_{ij}\, x_{ij} \begin{pmatrix} i = 1, \ldots, m \\ j = 1, \ldots, n \end{pmatrix}$$

the coefficients c_{ij} do not depend in any way upon x. In the contrary case, the problem would be of a different, more difficult type.

The cost c_{ij} must also include the cost of shunting in the departure and arrival stations for coupling and uncoupling the wagon to the train. The shunting depends on the characteristics of the stations, the number and original arrangement of the wagons, but it would be extremely difficult to try and take these extremely varied circumstances into account in a simple formula for c_{ij}. So that, at least until we know the average cost of shunting a wagon in each station, it is necessary to use a constant average cost per wagon in the consigning stations (5): later on we shall see when studying the problem that it is possible to leave out this constant data, since it applies to all transport of empty wagons.

The same observation applies to the cost of shunting at an intermediate station where the wagon has to change trains; this is taken into account for runs where such shunting is necessary.

The other cost factors all relate to the wagon as a unit. It is therefore legitimate to

(5) Conventionally, a wagon is considered as having been shunted solely when it leaves from the station in which shunting took place.

admit the hypothesis of the constancy of c_{ij}, at least in the same order of approximation as the figures supplied by the Central Administrative Department of the railway.

Later on, we shall see how to take into account variations in the above coefficient when passing from allocation covering wagons added to ordinary trains to allocation involving the running of special trains to send on empty wagons.

4. Characteristics of the transport problem and conditions that must be fulfilled by any practical method of solving it.

It is a question of finding practical forms of solution to the transport problem, i.e. finding the values x_{ij} which make the function (3) minimum :

$$C = \Sigma_{ij}\, c_{ij}\, x_{ij} \begin{pmatrix} i = 1, \ldots, m \\ j = 1, \ldots, n \end{pmatrix}$$

at the same time as they satisfy the relations (conditions of quantity) already given (1) and (2) :

$$\sum_{1}^{n}{}_{j}\; x_{ij} \leqslant a_i$$

$$\sum_{1}^{m}{}_{i}\; x_{ij} \leqslant b_j$$

and the condition (of kind) :

$$x_{ij} \geqslant 0 .$$

In the above formulae :

x_{ij} is the number of wagons sent from station O_i to station D_j;

c_{ij} is the unit cost (per ton) of doing this;

a_i is the number of wagons available at O_i;

b_j is the number of wagons asked for by D_j.

The characteristics of the problem are already well known; we will deal with them very briefly.

It is known that the inequalities (1) and (2) can be changed into equations by introducing the non-negative variables $X_{n+1,j}$ for the inequality (1), and $X_{i,m+1}$ for (2), so that :

$$\sum_{1}^{n}{}_{j}\; x_{ij} + x_{n+1,j} = a_i$$

$$\sum_{1}^{m}{}_{i}\; x_{ij} + x_{i,m+1} = b_j .$$

We will therefore suppose that the relations (1) and (2) are equations. Under this hypothesis, they are not independent, as if they are added together member by member, we get identity.

It is therefore possible to leave out one (at least) of the equations (1) and (2) which will therefore be reduced to $m + n - 1$ independent equations.

In the general theory of linear programmation, we call basic solutions of equations (1) and (2), those obtained by supposing that amongst the $m\,n$ variables, X_{ij} ($m + n - 1$) differ from zero and the others do not.

Obviously, the basic solutions are equal in number to the combinations of $m\,n$ factors $(m + n - 1)$ to $(m + n - 1)$; they are therefore numerous, even for relatively low values of m and n.

The most important result of this theory is this : the function « cost » has its minimum value precisely when it corresponds with a so-called *optimum* basic solution.

This being stated, what conditions must be met by a form of solution to the Hitchcock problem if it is to be adopted in the current practice of the railway ?

In the case of the problem with which we are dealing, it is necessary to take the following circumstances into account :

Knowing — generally late in the evening — the demands for empty wagons from the stations and the wagons available at the stations, each allocator first of all must make a precise analysis of both the demands for wagons and the wagons available, according to criteria dictated by his professional and local experience : this is a very important preliminary task which if it is to

be well done requires great assiduity and much abnegation.

He then proceeds to the formulation of the allocation programmes, a separate programme for each kind of wagon, and the transmission of the corresponding orders to the stations. This second part of the work takes a varying period of time according to the case, but is always brief; it sometimes only takes a few minutes. If it took longer it would make it more difficult for the stations to select and send off the empty wagons in good time.

Consequently, to be adopted as current railway practice, any method of solving rationally the problem of allocation at the minimum cost must meet the following conditions :

1) it must not involve any analytical calculations, but merely simple, brief arithmetical counts;

2) it must be adaptable to all circumstances which arise in railway practice, and allow of them being taken into account without complicating the solution of the problem.

* * *

The best known analytical method for solving the general problem of linear programmation (for transport in particular) is that of the « simplexus » in which a predetermined basic solution is the starting point, and after lengthy calculations and the establishment of successive tables (simplexus tables) the optimum solution is deduced.

It is true that the general method, in the case of the transport problem, receives important simplifications, but even the simplest algorithms used in this case, the « computational procedure » of Dantzig or the tower method, are not simple in conception, nor rapid enough in use *to be suitable* for current railway practice.

Naturally, we will exclude the use of electronic calculators, the cost of which would not be made good by the possible savings.

For the transport problem, a tabular method (6) has recently been reported, known as the « advantages » method.

We will give hereafter the analytical bases of this method in order to illustrate accurately its nature and possibilities.

5. Method of elementary advantages.

We have seen that in the general transport problem, the equations of conditions are divided into two completely similar groups.

Two equations of the first group, for example the ith and the jth and two equations of the second, the pth and the qth contain four common factors, namely :

$$x_{ip} \; ; \quad x_{jp} \; ;$$

$$x_{iq} \; ; \quad x_{jq} \; .$$

For example, the two first equations of each group have the four elements in common :

$$x_{11} \; ; \quad x_{12} \; ;$$

$$x_{21} \; ; \quad x_{22} \; .$$

Consequently, we can always return to this case, as under the present considerations, it is of no importance if we change the order of the equations of connection given.

We will now ask ourselves the question : is it possible to vary the 4 factors in question (7) in a fashion compatible with the equations of connection in such a way as to obtain a function of lower value ? What should the variations be ?

Let us call the variations of x : Δx. It will at once be apparent that the values of Δx must satisfy the equations :

$$\Delta x_{11} + \Delta x_{12} = 0 \; ; \; \Delta x_{11} + \Delta x_{21} = 0 \; ;$$

$$\Delta x_{21} + \Delta x_{22} = 0 \; ; \; \Delta x_{12} + \Delta x_{22} = 0 \; ,$$

which derive immediately from the equations

(6) *Ingegneria Ferroviaria*, No. 10, Oct. 1958, art. cit.

(7) Variations with a lesser number of varying factors are obviously not possible.

of condition. If we designate by $-\alpha$ the variations of x_{11} in other words Δx_{11} we get :

$$\Delta x_{11} = -\alpha \; ; \quad \Delta x_{12} = \quad \alpha \; ;$$

$$\Delta x_{21} = \quad \alpha \; ; \quad \Delta x_{22} = -\alpha \; .$$

Consequently, the 4 variables considered, become, the variation terminated :

$$x_{11} - \alpha \; ; \quad x_{12} + \alpha \; ;$$

$$x_{21} + \alpha \; ; \quad x_{22} - \alpha \; .$$

The quantity α appears to be transported, in the table of the solution considered, from the space corresponding to x_{11} to the space below corresponding to x_{21}; at the same time, an identical displacement, but in the inverse sense, takes place from x_{22} to x_{12}.

All the other variables remain unchanged.

The cost of the initial solution, for the part covered by the four variables selected was : $c = c_{11}\, x_{11} + c_{12}\, x_{12} + c_{21}\, x_{21} + c_{22}\, x_{22}$.

Its variation is :

$$\Delta c = -(c_{11} - c_{12} - c_{21} + c_{22})\, \alpha$$

in which α can always be taken as positive.

We want the cost to diminish; for this purpose it is necessary that :

$$(c_{11} - c_{21}) + (c_{22} - c_{12}) > 0 \; .$$

The difference $c_{11} - c_{21}$ is the elementary advantage obtained when the unit of transport instead of following the route from the start O_1 to the destination D_1, goes from O_2 to D_1. Going back to the table (fig. 1) representing the solution, and making use of an inappropriate, but expressive term, we get this variation when the unit of transport is taken from x_{11} and added to x_{21} and descends from space (1,1) to space (2,1).

The difference $c_{22} - c_{12}$ has a similar significance in the passage in the inverse direction from space (2,2) to space (1,2).

The variation considered is suitable if the algebraic sum of the corresponding advantages to the two opposite vertical displacements :

$$(c_{11} - c_{21}) + (c_{22} - c_{12})$$

is positive. A possible advantage along one of the two simultaneous displacements may be compensated by a greater advantage (in absolute value) according to another displacement.

Is it only possible to have displacements in the vertical direction, along the columns of the table of solutions ? The condition found:

$$(c_{11} - c_{21}) + (c_{22} - c_{12}) > 0$$

can also be written :

$$(c_{11} - c_{12}) + (c_{22} - c_{21}) > 0 \; .$$

It is evident that the first term is the advantage in the displacement (horizontally) from space (1,1) to space (1,2).

$$\begin{array}{ll} (1,1) & (1,2) \; . \\ -\alpha & +\alpha \end{array}$$

The second term gives the advantage in the horizontal displacement in the inverse sense from (22) to (21)

$$\begin{array}{ll} +\alpha & -\alpha \\ (2,1) & (2,2) \; . \end{array}$$

Under these conditions, the total displacement takes the form :

$$\begin{array}{ll} -\alpha & +\alpha \\ (1,1) & (1,2) \\ (2,1) & (2,2) \; . \\ +\alpha & -\alpha \end{array}$$

It is permissible to suppose that the starting factors of the displacement, in other words those from which the quantity α is removed, are always x_{11} and x_{22}, whether the displacement be effected horizontally or vertically.

These are therefore two factors of the solution belonging to *different lines and columns* in the table representing the said solution.

This is the veritable characteristic of the method : the consideration of the possible and suitable variations common to two values forming a *diagonal pair* whose indices, we repeat, belong to different lines and columns.

Generally, only vertical displacements in the table of solutions are considered; but it may at times be more convenient to consider horizontal displacements, i.e. variations in supplies to destination stations and not at consigning stations. The two aspects of the investigation are absolutely equivalent.

	D_1	D_2
O_1	C_{11} $x_{11} - \alpha$	C_{12} $x_{12} + \alpha$
O_2	C_{21} $x_{21} + \alpha$	C_{22} $x_{22} - \alpha$

Fig. 1.

We have supposed that the same quantity α is taken from the two factors x_{11} and x_{22}. As generally we start from a solution (non-optimum) with an excessive number of variables, the investigation to find the optimum solution means cancelling out one or several factors of the starting solution. α will therefore be taken as equal to the smaller of the two values x_{11} and x_{22}. If $\alpha = x_{11}$, we go from the form :

x_{11}	x_{12}
x_{21}	x_{22}

to the following one

0	x_{12}
x_{21}	x_{22}

in which one of the factors has been made nil and the others are :

$$x'_{21} = x_{21} + x_{11} ;$$

$$x'_{22} = x_{22} - x_{11} ;$$

$$x'_{12} = x_{12} + x_{11} .$$

We can therefore enunciate the following criterion for the systematic investigation into possible variations (which we will call of the first order) to be made between the pairs of values of a given solution in order to find another of lower cost.

A value of the first line is considered and is associated one after the other with all the other values in the different lines and columns.

To the pairs (*diagonals*) formed in this way, the rule of advantages is applied by displacing in the vertical (or horizontal) direction, as we showed above, the smaller of the two factors forming the pair, if this meets the position. If these operations result in values in the first line which are not nil, it has to be repeated with all the possible pairs, as we have already said above.

We then go on to the values of the second line, which must be associated solely with those of the following lines (third, fourth and so on...) since the associations with the values of the first line have already been made.

The operation is repeated for the values of the third line, which have to be associated with those of the fourth, fifth and so on, until we get to the values of the line before the last, which can only be associated with those of the final line.

	D_1	D_2	D_3	D_4
O_1	C_{11} x_{11}	C_{12}	C_{13} x_{13}	C_{14}
O_2	C_{21}	C_{22} x_{22}	C_{23}	C_{24} x_{24}
O_3	C_{31} x_{31}	C_{32}	C_{33} x_{33}	C_{34}
O_4	C_{41}	C_{42} x_{42}	C_{43}	C_{44} x_{44}

Fig. 2.

For example, if we consider the table of figure 2, which represents the allocation diagram for wagons from centres O_1, O_2, O_3, O_4 towards the stations D_1, D_2, D_3, D_4, in order to endeavour to find a more economical solution that the one given, the follow-

ing pairs of values should be considered above all :

— for the factors of the first line :

(x_{11}, x_{22}); (x_{11}, x_{24}); (x_{11}, x_{33}); (x_{11}, x_{42}); (x_{11}, x_{44}); (x_{13}, x_{22}); (x_{13}, x_{24}); (x_{13}, x_{31}); (x_{13}, x_{42}); (x_{13}, x_{44});

— for the factors of the second line :

(x_{22}, x_{31}); (x_{22}, x_{33}); (x_{22}, x_{44}); (x_{24}, x_{31}); (x_{24}, x_{33}); (x_{24}, x_{42});

— for the factors of the line before the last :

(x_{31}, x_{42}); (x_{31}, x_{44}); (x_{33}, x_{42}); (x_{33}, x_{44}).

If during the investigation, new factors are found, all the possible pairs for these must be reconsidered.

The evaluations of the differences between the costs, which are at the most three figure numbers, can easily be done in each case, during the investigation, without it being necessary to evaluate them at the beginning and indicate them in the table representing the allocation by means of arrows which makes it more difficult to read.

6. **The multiple diagonal groups.**

It is not sufficient, however, merely to consider the diagonal pairs to exhaust all the possible variations of the values of a solution in order to find the optimum solution.

There are more complex displacements covering more than two values in different lines and columns. We will show the origins of these and give the rules for systematically finding them.

To start with let us consider the factors common to the equations of row r, s, t, of the first group (1) and row u, v, z of the second group (2.)

We can always take it without prejudice that $r = u = 1$, $s = v = 2$, $t = z = 3$. The nine factors are therefore those of the first three lines and first three columns of the table in figure 3.

If the x of this group of nine values vary simultaneously, and the other values remain unchanged, the variations of the former should satisfy the equations :

$$\sum_{1}^{3}{}_i \ \Delta x_{ij} = 0 \ ; \ \sum_{1}^{3}{}_i \ \Delta x_{ij} = 0 \ .$$

There are 6 homogeneous non-independent equations between 9 unknown factors.

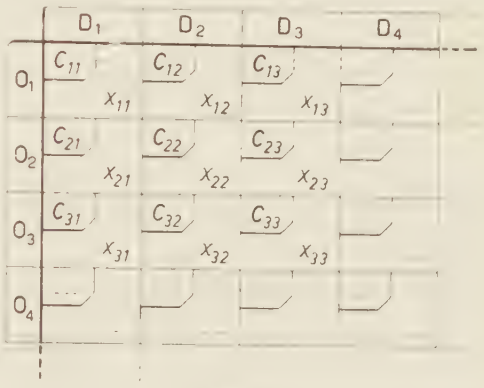


Fig. 3

Four of these unknowns can be fixed arbitrarily, for example Δx_{11}, Δx_{22}, Δx_{33}, Δx_{12}, and all the other values Δx be expressed as a function of the 4 former ones. We get :

$$\Delta x_{13} = -\Delta x_{11} - \Delta x_{12} \ ;$$

$$\Delta x_{23} = \Delta x_{11} + \Delta x_{12} - \Delta x_{23} \ ;$$

$$\Delta x_{21} = -\Delta x_{11} - \Delta x_{12} - \Delta x_{22} + \Delta x_{33} \ ;$$

$$\Delta x_{31} = \Delta x_{12} + \Delta x_{22} - \Delta x_{33} \ ;$$

$$\Delta x_{32} = -\Delta x_{12} - \Delta x_{22} \ .$$

Figure 4 shows the table of values after variation.

The increases in each variation can be considered separately and in succession. We can thus eliminate increases which form variations of diagonal pairs, which are :

Δx_{11} in : | x_{11} | x_{13} | ; | x_{21} | x_{23} |

Δx_{22} in : | x_{21} | x_{22} | ; | x_{31} | x_{32} |

Δx_{33} in : | x_{21} | x_{23} | . | x_{31} | x_{33} |

By eliminating these variants of the type already considered, we get the table of figure 5.

This shows a variation of a new type (which we will call of the second order) in which Δx_{12} is taken from three factors (x_{21} , x_{32} , x_{13}) in different lines and columns,

	D_1	D_2	D_3
O_1	C_{11} $x_{11}+\Delta x_{11}$	C_{12} $x_{12}+\Delta x_{12}$	C_{13} $x_{13}-\Delta x_{11}-\Delta x_{12}$
O_2	C_{21} $x_{21}-\Delta x_{11}+$ $-\Delta x_{12}-\Delta x_{22}+\Delta x_{33}$	C_{22} $x_{22}+\Delta x_{22}$	C_{23} $x_{23}+\Delta x_{11}+\Delta x_{12}-\Delta x_{33}$
O_3	C_{31} $x_{31}+\Delta x_{12}+\Delta x_{22}-\Delta x_{33}$	C_{32} $x_{32}-\Delta x_{12}-\Delta x_{22}$	C_{33} $x_{33}+\Delta x_{33}$

Fig. 4

and added, in compensation, to three factors (x_{31} , x_{12} , x_{23}) also in different lines and columns.

We call these terns *diagonal terns* because with the appropriate displacement of the indices of the lines and columns, we can always suppose that their factors are arranged along a diagonal (as for example x_{11} , x_{22} , x_{33}).

The particular form found for the possible variations depends on the choice of the parameters Δx_{11} , Δx_{22} , Δx_{33} by means of which all the other variations were expressed; by changing the parameters, other configur-

	$x_{12}+\Delta x_{12}$	$x_{13}-\Delta x_{12}$
$x_{21}-\Delta x_{12}$		$x_{23}+\Delta x_{12}$
$x_{31}+\Delta x_{12}$	$x_{32}-\Delta x_{12}$	

Fig. 5.

ations would be found. It will be seen that the variation (multiple) has as its origin a factor (x_{21}) of the second line, and ends with another factor (x_{23}) of the same line. This is suitable if the corresponding variation of the function « costs » :

$$\Delta c = (-c_{21} + c_{31} - c_{32} + c_{12} - c_{13} + c_{23})\,\Delta x_{12}$$

is negative.

We can always suppose that :

$$\Delta x_{12} > 0$$

so that the variation is suitable if :

$$(c_{21} - c_{31}) + (c_{32} - c_{12}) + (c_{13} - c_{23}) > 0.$$

The first member is the algebraic sum of the three advantages corresponding to the three vertical displacements forming the ternary displacement.

It is advisable to stop with the results obtained as regards the form of the probable variations of a group of nine factors (determined by three different lines and columns) of a table of solutions.

We have found a particular variation,

composed of three binary variants and one ternary variant of the type indicated.

But if we had adopted other variables as parameters for solving the system of homogeneous equations of the variations, we would have found other expressions for the variations of the nine values of x_{ij} considered.

For example, by adopting Δx_{11} , Δx_{12} , Δx_{21} , Δx_{22} , we would only find the binary and no longer the ternary variations. All these results are equivalent as solutions of the system of homogeneous equations, but they are in no way equivalent as regards the cost of transport.

Consequently, when we have a diagonal group of three tern values in an allocation diagram, it is necessary to evaluate all the ternary combinations of the corresponding coefficients of cost.

Les us consider, for example, in figure 6, the diagonal tern (x_{11} , x_{22} , x_{33}) of which we have previously spoken.

In how many different ways can we trace, starting from x_{11} , a multiple ternary displacement involving the two other factors x_{22} and x_{33} and terminating at the first line on which is x_{11} ?

Obviously in two ways, shown in figures 7 and 8.

In the former, the total advantage is :

$$(c_{11} - c_{21}) + (c_{22} - c_{32}) + (c_{33} - c_{13}).$$

in the latter, the advantage is :

$$(c_{11} - c_{31}) + (c_{33} - c_{32}) + (c_{22} - c_{12}),$$

different, in general, from the former.

This is why it is necessary to consider the two combinations so that the investigation into the suitability of the possible ternary variants is complete.

It could be supposed that the ternary variant had its origin in x_{22} or x_{33} rather than in x_{11} . The expression of the total advantages is identical with that already found.

Referring to the diagram of figure 2, we should, in investigating the possible advantageous variants, consider :

a) the diagonal tern starting from x_{11} , which are :

(x_{11}, x_{22}, x_{33}); (x_{11}, x_{22}, x_{44}); (x_{11}, x_{44}, x_{33}); (x_{11}, x_{14}, x_{42}); (x_{11}, x_{33}, x_{42}); (x_{11}, x_{33}, x_{44}); i.e. 6 possible terns and 12 runs;

b) the terns starting from x_{13} :

(x_{13}, x_{22}, x_{31}); (x_{13}, x_{22}, x_{44}); (x_{13}, x_{44}, x_{31}); (x_{13}, x_{44}, x_{42}); (x_{13}, x_{31}, x_{42}); (x_{13}, x_{31}, x_{44}); again 6 terns and 12 runs;

c) those which start at x_{22} (second line) with factors from the 3rd and 4th lines :

$$(x_{22}, x_{31}, x_{33}); \quad (x_{22}, x_{31}, x_{44})$$

which gives 4 runs;

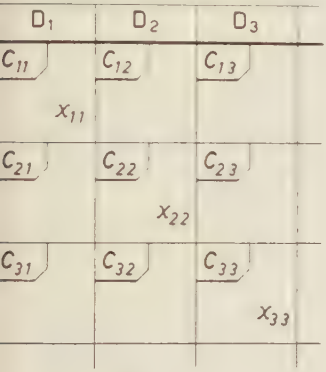


Fig. 6.

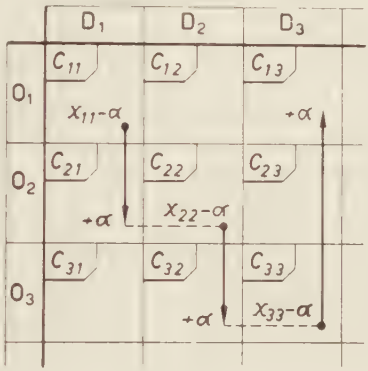


Fig 7

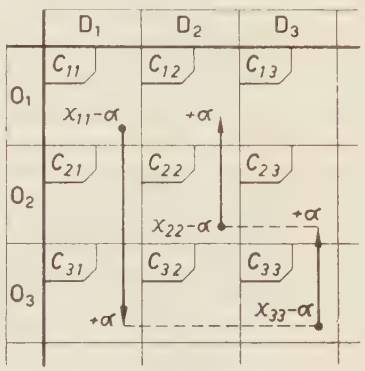


Fig. 8

d) and finally those starting at x_{24} :

$$(x_{24}, x_{31}, x_{42}); \quad (x_{24}, x_{33}, x_{42})$$

with 4 other runs.

In all, we have $12 + 12 + 4 + 4 = 32$ possible ternary combinations in a fairly simple allocation diagram.

Having determined in some way an advantageous variation affecting, for example, the three factors (in diagonal) x_{24} , x_{31} , x_{42} , the corresponding variation will be made taking the smallest as the term to be substracted.

Having made the variation, one (at least) of the three factors will be cancelled out.

* * *

By means of an investigation similar to that made for the ternary groups, we can find the variations (compatible with the equations of condition) of four diagonal factors, in other words situated in 4 different lines and columns of the allocation table (which we will call of the third order).

In the diagram of figure 2, these are the groups :

$$(x_{11} , x_{22} , x_{33} , x_{44}); \quad (x_{13} , x_{22} , x_{31} , x_{44});$$
$$(x_{11} , x_{24} , x_{31} , x_{42}); \quad (x_{13} , x_{24} , x_{31} , x_{42}).$$

The variations should have their origin in any one (for example the first) of the factors of the group. For each group there are therefore as many variants as there are permutations of the three factors, i.e. 6.

For example, the factors of the quarte $(x_{11} , x_{22} , x_{33} , x_{44})$ can vary in the manner shown in figure 9.

For each of these variants, the sum of the relative advantages with different displacements along the vertical must be calculated: if the sum is positive, the displacement is suitable.

For example, the 3rd form corresponds to the total advantage :

$$(c_{11} - c_{31}) + (c_{33} - c_{23})$$
$$+ (c_{22} - c_{42}) + (c_{44} - c_{14})$$

which, if it is positive, makes the corresponding quaternary displacement suitable.

An identical investigation must be carried out for the relative configurations of the other diagonal groups of 4 factors. In all, there are $4 \times 6 = 24$ configurations of this type to be examined.

When starting from a given initial allocation, and first of all making binary, then ternary, then quaternary, etc. displacements, the configuration generally varies progressively, and it is not possible to establish *a priori* how many possible displacements will have to be examined.

In any case, it is instructive to make a count of these groupings, even under the hypothesis that the starting configuration will remain unchanged during the operation. In the diagram of figure 2, it is necessary, with this hypothesis, to examine :

— 20 simple binary groupings;

— 32 ternary groupings;

— 24 quaternary groupings.

Consequently, an investigation into all the possible advantages may involve the examination of 76 different groupings of the values of the starting solution. Moreover, it must not be forgotten that if a binary displacement involves the evaluation of the sum of 2 differences (as an expression of the displacement itself) a ternary displacement involves the examination of the sum of 3 differences, a quaternary displacement the sum of 4 differences, etc. If, on the other hand, the initial configuration of the allocation varies during the investigation, for each variant it will be necessary to re-examine the new groupings.

From this, it will be appreciated how the number of possible combinations of costs to be examined will increase as the dimensions of the allocation table increase, in other words as the number of stations examined increases, both consigning and destination stations for empty wagons. We end up with such high numbers, and such complicated combinations that it would be useless to pretend that any railway operator could examine them all : it would involve lengthy and patient research work.

These considerations show the limitations of the method dealt with, which as a research method is not as good as the « simplexus » method or the other analytical methods suggested.

troduced, about which we shall speak later, it is always possible to arrange things in such a way that the allocation diagrams only have an acceptable number of lines and columns, in other words, the indeter-

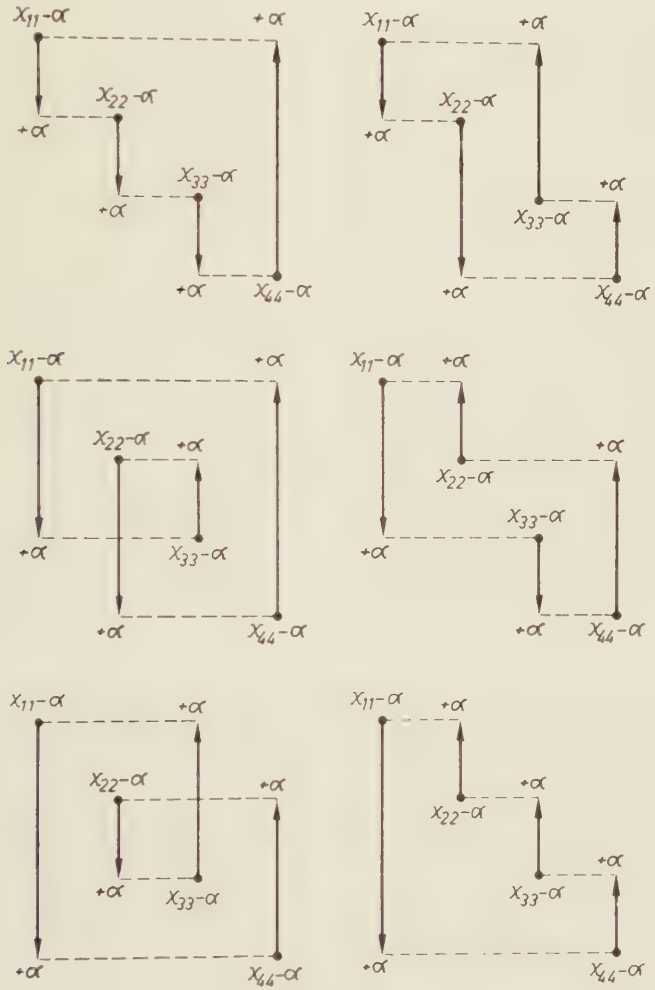


Fig. 9.

In practice, however, at least in railway practice, the conclusions are quite different. Experience has shown that provided preliminary simplifying considerations are in-

minate factors of the problem do not cover a large number of stations. In this way, the maximum order of the diagonal groups of values of the starting solution to be taken

into account is not high. In addition, in such simplified tables, the optimum solution is reached, in general, only by considering binary combinations or of the first order; once these have been exhausted, it is rarely necessary to have to make use of those of a higher order.

The reason for this is as follows : after examining all the possible binary combinations, and carrying out the corresponding advantageous displacements, the probability of finding anything suitable in a multiple displacement of a higher order is remote, and becomes the more remote as the order of the multiple displacement increases (ternary, quaternary, etc.) In practice, it is rare to find an advantageous ternary combination, and extremely rare to find a combination of a higher order, in other words covering 4 or more diagonal factors of the allocation table (this, naturally, after making use of the binary and ternary associations).

To stress these facts, let us consider in figure 10 an allocation diagram covering 3 consigning stations (A, B, C) and 3 destination stations (X, Y, Z).

We have shown in each case the cost of the consigning. If we take it that we must start with an initial allocation in which all the spaces are occupied, in other words in which each consigning station takes part in sending wagons to the destination stations (and such an allocation could not be at minimum cost), it can easily be seen that there is at least one diagonal group of values x_{ij} in which a ternary displacement could be made to obtain allocation at lower cost.

But when to begin with all the possible binary displacements due to the consideration of the diagonal pairs have been carried out, the allocation arrived at will no longer be identical with that with which we started: certain factors will have become nil, and there cannot be 4 adjoining spaces with values of x_{ij} all different from zero.

Its form will therefore be of the type indicated in figure 11.

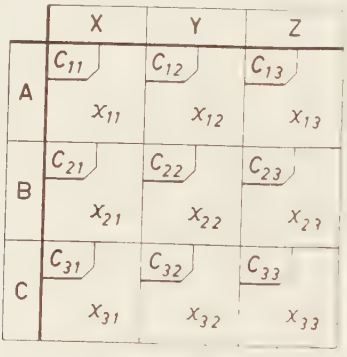


Fig. 10.

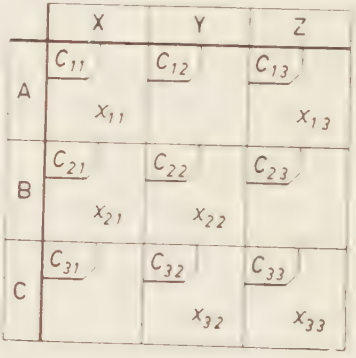


Fig. 11.

This cannot be of minimum cost, because it includes 6 values which are not nil, instead of 5 $(= 3 + 3 - 1)$. This means that there must be at least one suitable ternary displacement; this concerns, for example, the diagonal group $(x_{11}, x_{22}; x_{33})$, which leads to a new form of minimum cost. But for this to be the case with the ternary group in question, no binary displacement affecting the values of this group must be suitable, in other words there must be the following three inequalities, which show the unsuitability of the binary displacements :

$$(c_{21} - c_{11}) + (c_{12} - c_{22}) < 0;$$
$$(c_{31} - c_{11}) + (c_{13} - c_{33}) < 0;$$
$$(c_{32} - c_{22}) + (c_{23} - c_{33}) < 0;$$

and at the same time one of the two following

inequalities, of opposite sign to the former, which shows the suitability of a ternary displacement in the group (x_{11}, x_{22}, x_{33}) :

$$(c_{21} - c_{11}) + (c_{32} - c_{22}) + (c_{13} - c_{33}) > 0,$$

or else :

$$(c_{31} - c_{11}) + (c_{23} - c_{33}) + (c_{12} - c_{22}) > 0.$$

These conditions are facts which have a probability below unity; consequently, the probability of the resulting fact (i.e. a suitable ternary displacement after all the binary displacements) is very small. This means that another consignment (at least) x_{ij} of the preceding table is cancelled, in most cases, after carrying out all the possible binary displacements.

Even more numerous are the conditions that have to be checked before finding, in an allocation diagram of bigger dimensions than the preceding one, a quaternary displacement which is suitable, after exhausting all the binary and ternary displacements to be considered : the probability of such a displacement being suitable is so small that it can be considered as practically nil. In substance, if it is desired to find in an allocation diagram a diagonal group of 4 values which can still have a suitable displacement, after exhausting all the possible binary and ternary combinations, the cost figures must be adapted to this end.

During several months of experiments carried out on the allocation plans of the Naples Region, on only a few occasions did we find an admissible ternary displacement, after having exhausted the whole range of binary combinations, and we never found any suitable displacements in the groups of a higher order.

Consequently, the method suggested, which in theory may call for numerous reservations, is very effective in practice, and can be adopted with the certainty of nearly always reaching its objective (i.e. allocation at minimum cost) merely by an examination of the binary combinations, which is very convenient because this only involves estimating differences between numbers having at the most 3 figures.

In a very short time, one becomes so expert in carrying out this examination, that it can be done very rapidly.

The ternary combinations in themselves are not difficult to examine if the operator is sufficiently experienced; in any case, this has to be done in particular when the allocation obtained with displacements of the first order is manifestly not of minimum cost owing to the excessive number of values which are not nil and when there are consignments in the spaces of insufficiently low costs.

It must also be stated that, to facilitate such investigations the choice of the initial allocation is of great importance, and it must always be close to that having the minimum cost.

In practice it is possible to adopt an allocation obtained according to the criterion now followed by the allocators, i.e. minimum empty runs; a still better allocation is that obtained by endeavouring to fill the spaces with the lowest costs.

Consequently, the method suggested is, in current practice, the most natural way of solving the transport problem. If an attempt is made to use it for solving one of the numerous examples given as model solutions with other analytical methods by investigators who have dealt with this problem, it will be seen that the results obtained by these latter after lengthy calculations can be attained by a few trials and nearly always merely by examining the binary combinations alone.

To advise the use of analytical methods in dealing with the transport problem is like asking a gardener to draw out an ellipse through points on the ground by using the cartesienne equation, instead of taking two pegs and a sufficiently long length of string.

Further on, we will show that the tabular method of elementary advantages is so flexible, so easy to adapt to all conditions in practice (by making it easy to obtain allocation under minimum conditions) that in this respect it is far superior to analytical methods.

7. The simplified criteria of the transport problem in railway practice.

These criteria, which make investigation of allocation at minimum cost more easy,

result immediately and simply from the equations of condition and of cost of the problem, which we will transcribe here :

$$\sum_{1}^{n}{}_{j}\, x_{ij} = a_i; \qquad (1)$$

$$\sum_{1}^{m}{}_{i}\, x_{ij} = b_j; \qquad (2)$$

$$C = \Sigma_{ij}\, c_{ij}\, x_{ij} \text{ (minimum)}. \qquad (3)$$

a) *Criterion of the proportionality of the costs.*

A first criterion, in verity more theoretical than practical, derives from the fact that if all the costs c_{ij} vary according to a constant factor k, in other words if each c_{ij} becomes kc_{ij}, the new function cost C′ allows the same minimum point as the primitive function C (because $C' = kc$).

Therefore, if the costs were proportional to the real distances between the stations, we could allow precisely as costs the real distances. But there is no such proportionality, and the costs vary rather according to the virtual distances. These latter cannot be taken as costs, because the shunting done by the wagons in the stations, either on departure or during the run, falsify this proportionality, and because this coefficient of proportionality varies according to the direction of running on the line.

b) *Criterion of the increase in the costs.*

This is due to the following observation, similar to that made under point *a*) above, if all the costs c_{ij} increase by a constant factor k, the new function cost is :

$$C' = \Sigma_{ij}\, (c_{ij} + k)\, x_{ij} = C + kM$$

in which M represents the total number of empty wagons to be allocated (and accepted) It is obvious that the minimum of C′ lies at the same point as that of C.

This observation enables us to leave out in calculating the costs all increases which do not vary with the modalities of the allocation, in other words with the run made by the wagon. It is even possible to leave out the cost of shunting at the departure station if this is taken as being the same for all the wagons. If on the contrary, this cost varies from one station to another (as would be the case if the investigation were carried further), its values in the different stations must be taken into account.

In evaluating the costs, we should only consider increases essential to the purpose of the problem so as to limit ourselves to low figures, with which it is easier to appreciate the differences immediately.

c) *Criterion of superimposed consignments.*

We called those consignments superimposed which follow the same route over a certain section at the beginning or end of a run. In this case, their costs will differ by the quantity (k) relating to the part of the run which they do not make in common, and if this circumstance is verified for all the possible runs from (or to) a station compared with those from another station, we get :

— in the case of two consigning stations A_r, A_s :

$$c_{ri} = c_{si} + k;$$

— in the case of two destination stations :

$$c_{jr} = c_{js} + k.$$

The costs of two lines of the allocation table, in the first case, and two columns, in the second case, differ by the constant quantity k.

Let us consider the first case and see the resulting consequences for the expression of the function cost :

$$C = \Sigma_{ij}\, c_{ij}\, x_{ij} \left(\begin{matrix} i = 1, \ldots, m \\ j = 1, \ldots, n \end{matrix} \right).$$

In the summation, the terms corresponding to the line of row r are given by the sum $C_r = \sum_{1}^{n}{}_{i}\, c_{ri}\, x_{rj}$ and as $c_{rj} = c_{sj} + k$, this sum becomes :

$$C_r = \sum_{1}^{n}{}_j (c_{sj} + k)\, x_{rj} = \sum_{1}^{n}{}_j c_{sj}\, x_{rj} + k\, a_r$$

in which a_r is the number available from station A_r.

If we observe that the terms of the line of row s are given by $C_s = \sum_{1}^{n}{}_j c_{sj}\, x_{sj}$ and if we add this expression to the preceding one, we see that the function « costs » consist of two increases :

— a constant increase ($k\, a_r$) which has no influence on the determination of the minimum;

— a residual increase in which the terms corresponding to the two stations A_r and A_s are combined in a single term $\sum_{1}^{n}{}_j c_{sj} (x_{rj} + x_{sj})$, which can be considered as relating to a hypothetical station A with the same costs as A_s and as variable of the consigning x_{ij}, the sum $x_{rj} + x_{sj}$ of those corresponding to the two separate stations A_r and A_s. In other words, it is lawful to suppose, *with the sole object of finding the minimum cost*, that the station A_r is one with A_s (or vice-versa) and its available numbers can be added to those of this latter.

The function cost, consequently, does not depend separately on the variables x_{rj} and x_{sj} but on their sum $x_{rj} + x_{sj}$; we can therefore suppose that wagons are consigned indifferently from one or other station, within the limits, naturally, of their actual available numbers.

Similar conclusions are arrived at in the second case of the two destination stations D_r and D_s for which the costs on arrival differ by a constant quantity. They can be considered, always from the point of view of the problem with which we are dealing, as combined into a single station (one or the other) having requirements equal to the sum of their individual requirements.

From these results, we get a consideration that is of importance in railway practice. If a consigning station A can only take part in the allocation through the intermediary of the consigning station B, and if all the consigning itineraries starting from A undergo the same process at B as regards shunting (there must not in consequence be one itinerary involving shunting and one which does not), the allocator can take it that he needs only consider station B from the point of view of investigating the minimum with numbers available equal to the sum of those available at A and B.

A similar simplification can be made in the case of a destination station A which can be supplied solely through the intermediary of station B.

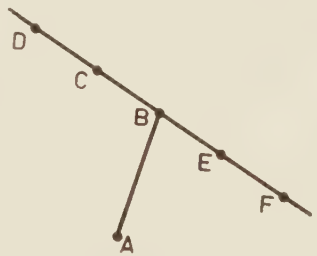


Fig. 12.

And the problem (fig. 12) of allocation on a section of line A-B ending at a junction station B can be considered by itself, i.e. separately from that of the whole of the other stations C-D-B-E-G-H-F, etc. provided that at B all the itineraries starting from or ending at the stations in this section do not differ from the point of view of the shunting involved.

The allocator can also apply the algorithm of elementary advantages on a table having compared with the original table a smaller number of lines and columns; the interest of this can be seen in connection with the rapidity with which the optimum allocation at minimum cost can be calculated.

8. Special conditions when allocating empty stock.

Numerous circumstances may arise and affect the daily task of the allocator. The

allocation of empty stock cannot always take place with an uniform character, as may be the case for consignments of goods from the centres of production, but the tabular method makes it easy to take into account all the aspects and conditions under which this allocation must take place.

We will list the most characteristic situations and mention briefly the rules for solving the problem in these different cases.

1) *Surplus wagons.*

In this case, the equations of condition (1) are inequalities, and we have stated that they can be restored to equalities by introducing new positive or zero variables $x_{n+1,j}$.

In working with the method studied, this way of working amounts to adding to the allocation table a column « S » (this being the initial letter of « slack », a term by which American authors designate *inactive* variables) in which are listed the quantities of wagons remaining unused, owing to surplus stock, in stations where empties are available. To apply the method being studied, the costs to be entered in the spaces of column « S » are all equal to zero, because they refer to wagons that are not being moved. As far as the rest goes, column « S » must be considered as representing a hypothetical station (destination) for the immobilised stock.

2) *Shortage of wagons.*

In this case, the equations (2) are inequalities, and they can be changed into equalities by introducing new positive variables $x_{i,n+1}$ in an altogether similar fashion to that of paragraph (1) above.

This amounts to adding to the table of consignments a line corresponding to a hypothetical station $\mathcal{J}$ with insufficient or short stock : this station proceeds with the allocation of the missing wagons (this is not a joke) so that the allocation of those wagons that really exist can be done with the minimum cost.

The corresponding costs for consignments from $\mathcal{J}$ station are all zero.

However, the method in question is not always acceptable in railway practice, because it leads to supplying preferably those stations closest to those with wagons to spare. Such a method of working may suit the railway, but will lead to protests from clients at many stations who are constantly neglected from the point of view of allocation and thereby seriously deprived of a chance to load their goods. Therefore, it is necessary first of all (with the assistance of a factor of proportionality or following some other criteria) to reduce all the demands so as to make the needs agree with the real number of wagons available, and then proceed in the usual way.

3) *Obligatory services.*

It may happen that lacking a suitable train, imperious loading requirements or other reasons make it necessary to meet, wholly or partly, the empty wagon requirements of a given station D_s from a consigning station O_r. Analytically, this amounts to fixing in advance, in the equations of conditions (1) and (2) and in the function cost C, the service variable x_{rs}.

The tabular method for finding the most economical allocation retains its full validity when the condition indicated is respected. The result is that starting from a given initial allocation (8), during the course of the investigation, all compensating movements between the consignment figures that may be shown in the line of row r and those in the column of row s are forbidden, because these would cause a variation in the predetermined value of x_{rs}.

We then obtain an allocation of minimum cost which is not absolute but relative, and the imposed condition is usually detrimental. This consideration shows that such a con-

(8) Such an allocation may be obtained, for example, with the rule that theorists call « the north-west corner rule ». But it is preferable to adopt an initial allocation with which those spaces are occupied to the greatest extent possible for which the costs are lowest in the allocation table, so as to have an allocation as close as possible to the minimum cost.

dition, and all others of a different nature in the transport problem, must be avoided as much as possible.

4) *Prohibited services. Clearance conditions at a station.*

It is a question of avoiding a consigning station O_r sending empty wagons to station D_s. Such a necessity may be due to the lack of a suitable train, excessive journey times, etc.

The space (r, s) on the allocation table then becomes a *prohibited space*, and no value x_{rs} must be shown on it.

The condition of prohibiting consignments is equivalent to establishing that $x_{rs} = 0$ in the equations of conditions (1) and (2) and in the function cost C.

In this case once again, we obtained conditional allocation of minimum cost, which from the point of view of economy of transport does not equal absolute minimum costs.

The idea of a prohibited space is of great importance in the case where such a space comes in the column « S » of wagons immobilised owing to excess stock. In this case, no wagon should figure in the prohibited space, in other words no wagon should remain immobilised in the consigning station to which this corresponds. In this way, we obtain allocation at minimum cost together with the *condition of clearance* of the station : this is a frequent necessity in railway practice.

The condition of clearance can obviously be completely satisfied so long as the number of wagons available at the station to be cleared is not greater than the requirements of the stations to be supplied.

It is obvious that it might be desired to obtain partial clearance of the station : in this case, the number (fixed) of wagons remaining therat and which will be deducted from the number available should be shown in the case.

		VALLE di MADD.	CAN-CELLO	NAPOLI SMIST.	S
		15	30	45	(25)
BENEVENTO	45	61 / 15	110 / 30	133	casella proibita
CASERTA	30	11	11	34 / 20	10
TORRE A.C	25	142	60	29 / 25	
SALERNO	15	206	169	112	15

Fig. 13.

		VALLE DI MADD.	CANCELLO	NAPOLI SMIST.	S
		15	30	45	(25)
BENEVENTO	45	61 / 15	110 / 30	133 / 5	0 / 25
CASERTA	30	11	11 / 30	34	0
TORRE A.C.	25	147	60	29 / 25	0
SALERNO	15	206	169	112 / 15	0

Fig. 14.

We give in figures 13 and 14 a simple example of allocation with total clearance of a station (Benevento), comparing this with allocation not involving the condition of clearance.

In figure 13, Benevento allocates all its 45 wagons and remains clear of empties and the spare wagons are to be found on the contrary in the stations at Torre Annunziata Central and Salerno. In figure 14, Benevento only allocates 20 wagons and retains the other 25. According to the cost figures given, allocation with the condition of

clearance involves, compared with the other, an additional cost of 10 440 Liras taking it that the wagons concerned are high sided open wagons.

* * *

In the case of allocation with a shortage of stock when it is not desired to apply proportional reduction of the demands for wagons dealt with in paragraph 1), a prohibited space on line $\mathcal{J}$ of the shortages is equivalent to the condition of a complete supply for the destination station in the corresponding column. Naturally, the requirements of this station must not exceed the real number of wagons available.

Another practical method of working could be as follows : select certain stations whose requirements are to be met in full, and apply the rule of reduced requirements to the others.

The notion of prohibited spaces appears equally fruitful in practical applications. For example, experience soon teaches the allocator which services are never carried out under given conditions. He can then save himself the trouble of indicating the costs in the corresponding spaces, which will be *prohibited a priori*, and this will moreover result in the additional advantage of having a lesser number of compensating movements to consider in ascertaining the most economic allocation.

5) *Simple concentrations.*

When there is a daily surplus in a Region of a given kind of wagons, the Central Service may decree that this surplus be concentrated in a station having suitable installations so that they can be forwarded to regions needing this type of wagons.

It is then necessary to find the allocation at minimum cost meeting the condition that all the surplus wagons are sent to the station selected for this concentration of wagons. The problem, which is always a problem of conditioned minimum is easy to solve.

The regional surplus is given by $\varepsilon = \sum_{1}^{m} a_i - \sum_{1}^{n} b_j$ with the usual notations. It suffices to suppose that the station selected has requirements equal to ε and then proceed in the usual way.

To show the analytical character of this circumstance, we might say that we are always faced with the problem of a surplus of stock, as in paragraph 1), but in this case we do not attribute the zero costs to the positive variables $x_{n+1,j}$, but the cost of the consigning to the concentration station.

The allocator must not lose sight of the fact that he must favour the movement of empty wagons towards the concentration station; this often makes it possible to find the most economical allocation straight away.

6) *Multiple concentrations.*

The tabular method also lends itself perfectly to solving the problem of multiple concentrations, when there are several concentration stations. The greatest difficulty, compared with the previous case, lies in the fact that it is not known *a priori* how the surplus wagons are going to be allocated.

This difficulty is however soon overcome.

Let us consider in figure 15 the allocation table in which D_1 and D_2 are concentration stations, whose *total* requirements are equal to ε. Let us also consider a consigning station, for example O_1 from which the cost of forwarding wagons to D_1 and D_2 are c_{11} and c_{12}.

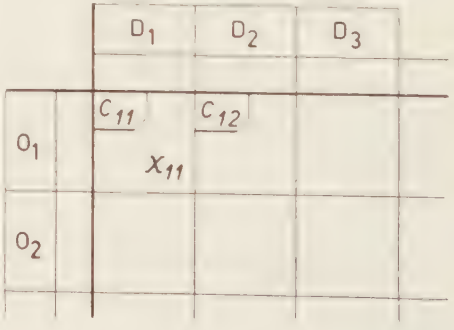


Fig. 15.

Finally let us suppose that $c_{11} > c_{12}$.

If the most economical allocation means consigning x_{11} from O_1 to D_1, as it is not established *a priori* how many wagons must go to D_1 and how many to D_2, there is nothing to prevent us supposing that the service will be made to D_2 with lower transport costs; the quantity x_{11} is then moved to space corresponding to D_2. In general, between two spaces in the columns of D_1 and D_2 on the same horizontal of row r and having costs c_{r1}, c_{r2}, the possible consignments for the concentration should come in

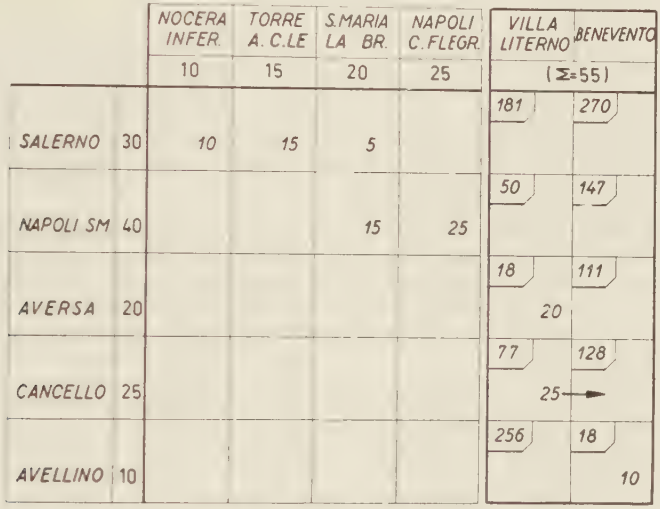


Fig. 16.

the space with the lowest cost. All that is necessary then is to make use of the usual method, taking instead of stations D_1 and D_2 a hypothetical station needing wagons ε which, in the space of line r has the *lowest* costs c_{r1} and c_{r2}.

At the end, that station will be taken into account to which the cost c_{rs} of the line in which there is a consignment x_{rs} towards the hypothetical point of concentration corresponds.

In the equations of condition (2), those which correspond to the two concentration stations (which we suppose to be rows r and s) are now replaced by a single :

$$\sum_{1}^{m}{}_i \; (x_{ri} + x_{si}) \; = \; \varepsilon$$

We have said this to show how easily the tabular method permits to overcome all these analytical complications.

We give in figure 16 an example of the most economical allocation with two concentration stations, Villa Literno and Benevento.

And if the allocator considers the number of wagons (10) which according to the principle of maximum economy is concentrated at Benevento, he can decide to forward others from Cancello, involving an increased cost of $(128 - 77) = 51$ Liras per ton, which would be lower than if they were sent from Aversa : (L. $111 - 18$) $= 93$ Liras.

It is evident that these latter displacements meet a *new criterion*, that of particular indetermination of requirements, which the tabular algorithm used so far has consequently not taken into account.

7) *Flows of empties.*

The subdivision of the national field of allocation of empty wagons into regional circumscriptions, due to functional necessities, is not without its drawbacks. On the national plan, it is possible to carry out allocation which is the result of the regional surpluses and shortages, and to control the movement of empty wagons, even in complete train loads, but the local allocator cannot take this into account in his own working diagrams. In this case, it is possible to have crossings of stock on the same line, and in any case the absence of co-ordination between the two allocations, national and regional, would certainly be anti-economic.

The problem is a serious one, and cannot be completely solved by amalgamating the local circumscriptions into one single one embracing the whole of the railway system. In any case, it would not be possible to do so on account of the difficulties this would cause to the Central Service both as regards obtaining the necessary information, and transmitting its orders. Such an allocation would moreover be so complex that it could only be carried out by means of electronic calculators.

The local manifestation of national allocation consists of the flow of empties. During many months of the year, certain main lines are run over by complete trains of empty wagons, in particular those for foodstuffs, and the local allocator taking part in this phenomenon must keep it in mind in order to harmonise his own work with it as best he can.

Obviously, it is a question of establishing a local criterion giving preference to movements of empties in the direction of this flow, and to reduce to the minimum those which necessarily must go in the opposite direction.

It is possible to establish such a criterion by adopting suitable conventions in the formulation of the consigning costs which, in the case of wagons of the same kind as those which are the subject of the flow of empties, will differ from the usual costs. We will not linger on this point, but merely point out that the allocator will find these *conventional costs* already calculated in the scale of which we have spoken.

8) *Association of allocation circumscriptions.*

The tabular method makes it very easy to demonstrate that any temporal or geographical association between two or more allocation circumscriptions makes it possible to obtain allocation at a cost equal to or less than the sum of the costs of the allocations of which it is made up :

$$C \leq C_1 + C_2 + \dots$$

If it is a question of an association in time, a practical rule of great importance can be deducted : the allocator must always take into account the characteristics of the allocation in the following days, if this is of predominant importance, so as not to make any allocations which will be in contradiction therewith.

If the association is a geographical one, the already known rule of the necessity for agreement between the allocators of the two adjoining circumscriptions in the case of all movements affecting zones near the frontier stations between one circumscription and the other must be confirmed and defined.

9) *Allocation with variable costs.*

The enunciation is in flagrant contradiction with the theory of the Hitchcock problem, founded on the hypothesis of independence between the costs and the consigning variables x_{rs}.

It may happen however that the optimum allocation, obtained from the hypothesis of variable costs for wagons added to ordinary trains, involves the running of complete trains of empty wagons, which will result in a much higher unit cost than the previous one.

Let c_{rs} be the cost which must be increased to become c'_{rs}.

If the allocation R already found does not undergo any variations with the new cost c'_{rs}, it remains the minimum cost. If on the

contrary, the allocation R varies and becomes R′, the needs which involved adopting c'_{rs} remaining unaltered, there is nothing to be done but take note of the variations (which is the most frequent case). But if with the new allocation R′, there is no longer any necessity to adopt c'_{rs} (which consequently becomes c_{rs}), a comparison must be made between the cost of R′ which is not an optimum allocation and the cost of the allocation R corresponding to the hypothesis of complete trains, and preference will be given to the least costly.

Conclusion.

The tabular method of solving the transport problem is easy to use in practice on condition that a complete scale of costs is available so that these can rapidly be entered on the allocation table : such is the result of the experience already obtained.

Having said this, what benefits can be hoped for from the adoption of the new method ?

The fact of giving allocators a means of complying exactly with the requirements of article 24 of the « Rules for the Allocation Service » which makes it obligatory to obtain the optimum allocation is perhaps not very important in itself, because the practical solutions are very close, in general, to the optimum solutions, but it is very important as regards its pedagogic and disciplinary consequences.

So far it has been obligatory for allocators to find that allocation having the minimum number of real wagons-km, but they are not told how they should do this. Consequently, the quality of the Allocation has depended upon the skill and diligence of the allocator, and not on precise rules making it possible to check that it has been properly done. In fact, allocation is the field in which employees have the greatest freedom of action.

With the new methods, all the allocation diagrams will be translated into tables, and it will be possible to check them daily : this is the first benefit.

A second and more substantial benefit will result from the local study of shunting and transport costs, because the local costs will gradually be substituted for the general average costs for the whole of the system. It will therefore be necessary to explore more thoroughly the little known field of local costs, so that the new methods can have an undeniable up-to-date value.

A better knowledge of local costs will make it possible to obtain allocations of real minimum cost, and fully justify the adoption of the new norms, which will moreover also improve the professional qualifications of the allocators.

« Instructions » are soon to be published, in which the theoretical rules will be given in an easily understandable form, with the smallest possible number of theoretical enunciations, and with examples for each case. Practical experience is soon to commence in the Regions of Naples, Palermo, Florence and Bologna, as soon as the scale of costs and instruction of the staff have been completed.

[385 (07 (71)]

CNR sends officers to school.

(*International Railway Journal*, October, 1960.)

Railway organizations can generally be pictured as an equilateral triangle divided into three layers — the bottom layer comprised of the more numerous skilled employees; the center layer consisting of supervisors and so-called middle management; and, at the top, the executives who set policy and direct operations.

Efforts to obtain most efficient use of plant and facilities are today placing new emphasis on the role of the middle group. Effective line supervision is essential if prescribed operating and service goals are to be achieved. Moreover, on most rail systems, this middle group provides a pool of talent from which future executive needs can be met.

Recognition of these principles has led a number of railways in North America to establish special training programs to improve that quality of the mid-management group. The Canadian National Railways have such a program — embracing, among other things, an annual six-weeks' school attended by fifty selected officers from all departments.

The C.N.R. school seeks to train these men in problem-solving techniques to help them in their positions and in their grasp of management functions. More important, the instruction is designed to help « students » recognize personal strengths and weaknesses and thereby to develop the ability to think clearly and administer wisely.

Fifty Canadian National officers at the end of the third week in July completed the company's six-weeks' staff school program, at Bishop's University, Lennoxville — in the scenic Eastern Townships area of Quebec province, about 100 miles east of Montreal. This is the eighth year of the staff school — the company now has approximately 400 officers (mostly of the middle management category) who have had the benefit of this educational experience.

The school is unusual among railways in North America in that instruction is given not only in management problems common to all business, but also in specific railway problems.

Educational programs of one kind or another, for managers and supervisors, are provided, with greater of less intensity, by most of the larger railways of North America. Some of the instruction is available only to higher management, but as far as numbers of railway officers included goes, emphasis has been directed to middle management. For the higher officers the customary program has been to arrange to have them attend an « advanced management » program — either at one of several large universities or at classes offered by the American Management Association. These « advanced management » courses cover questions common to the management of all businesses, with no particular attention to railroad problems. There are several universities (notably Stanford in California and Northwestern at Evanston, Ill.), where specific education is afforded in annual programs of several weeks' duration.

The main advantage which many attribute to the « advanced management » courses in universities is that they give railroad people intimate acquaintance with managers of other industry. The program of the Canadian National Railways, being restricted to its own people, does not provide this « outside » acquaintance. On the other hand, it does direct the attention of students to specific railroad problems — particularly those of the Canadian National itself.

The Canadian National (owned by the government of Canada, but organized as an independent corporation) is a huge railway system — over 39 000 km of route — extending all the way from Newfoundland in the East to British Columbia on the Pacific — and from Chicago on the South to Hudson's Bay on the North. With a system as far-flung as this, there is naturally a problem of interterritorial and interdepartmental acquaintance; and to bring into sharp perspective the human, economic and technological forces involved in management functions; and to train railway officers in the broad principles and techniques of modern business management and their application to the railway as a whole. Another aim of the Course is to help the student to know himself, his strengths and weaknesses, and to help him to take the proper direction in order to develop the ability to think logically, ex-

« Students » arrive at Bishop's University, Lennoxville, to begin six weeks of study.

the staff school helps to solve it. Probably, for middle management on such a railway as C.N.R., intracompany acquaintance takes precedence in importance over the desirability of « outside » contacts with other industry.

The purpose of the staff school is twofold : 1) by a careful process of screening of potential talent in middle management jobs, the school program gives management desirable information on individuals most likely to profit from this educational opportunity and 2), once these likely candidates are located, the school gives them instruction and impetus for selfimprovement. The company's statement of the aims of the school reads in part as follows :

« The Staff Training Course is designed

press himself clearly and administer wisely. »

Expert teachers from leading universities conduct courses in standard management subjects at the school. But the selection of the students and the administration of the program is strictly an « inside job » of the C.N.R. management. The activity is directly headed by W. T. Wilson, vice-president, personnel.

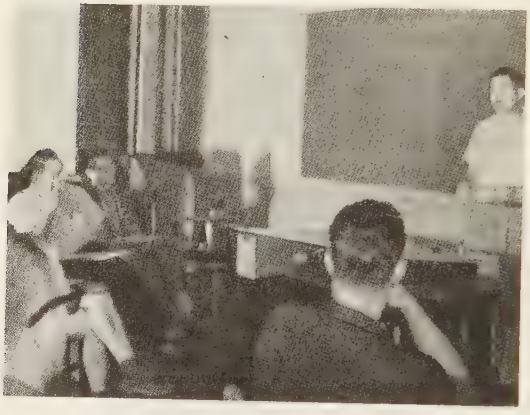
Each annual session has a « co-ordinator » — who, in a usual academic set-up, would be called a dean. Since the first session of the staff college, the man chosen as co-ordinator has invariably been one who has gone through the program himself; and the year before he takes over as co-ordinator, he spends a lot of time on the job with his predecessor, « learn-

ing the ropes ». The co-ordinator for the 1960 session was W. G. Hinkel, an officer of the passenger traffic department.

The « senior committee » in charge of the program is made up of the president (Donald Gordon); the vice-president personnel (W. T. Wilson); and the vice-president, research and development (Dr. O. M. Solandt).

There is, in addition, a « selection board » which is headed by the co-ordinator of the approaching session, assisted by other company officers. The co-ordinator travels over the system and personally interviews the individuals named as candidates. The names of the candidates are proposed by the vice-presidents and department heads, and interviews are set up at various points on the system — a process requiring from two to three months of the co-ordinator's time. But, by the process, the co-ordinator becomes personally acquainted beforehand with all his students.

To be considered as candidates, the supervisors chosen must 1) belong to the category of middle management, 2) show



Course opens with orientation classes.

Mobile equipment checks examination papers at end of the course.

some supervisory ability by actual experience and 3) preferably, be under age 45. (The actual average age has varied from 37 to 40. The average age of the 1960 class was 38, and the average years of service 15.)

Appraisal is systematic and includes ratings on physical qualities, personality, facility of expression, qualities of mind, interest and « general impressions ». Ratings are given on work records and « growth potentional ». Candidates who do not come up with a certain minimum number of points are usually disqualified. Sometimes those who do qualify cannot be accommodated in the year they qualify (since the school is limited to 50) — in which case they are given preference in selection the following year.

The instruction is divided into four main sections : 1) railway operations; 2) modern principles of business administration; 3) labor relations; 4) written and oral English. There are, also, occasionally lecturers from leading « outside » industries, patrons of the railway's services.

The instruction about the railway is provided, in the main, by some dozen of the company's officers — each of whom presents lectures and answers questions on the work of his department.

The business administration and labor relations instruction is given by several professors from universities, specially recruited for the occasion — experts in administrative practices, controls and financial management and marketing. The lecturer in labor relations brings the students up to date on the labor union movement in North America — especially in industries other than railroading, to enable the students to find instructive similarities between labor trends in other industries and those of the railways.

Standard textbooks are used for the management and labor relations courses, where such texts are available, and as much of the instruction as possible is given by the « case method » — the study of actual management problems confronted by specific companies.

A new feature of instruction, introduced at the 1960 session, was that of « business games ». In these games, the students are divided into a half-dozen or so teams, which are given typical problems of business policy to decide (quantity of production, price, research expenditures, and so on). The results of each group's decision are worked out on a computer — which determines which decisions yield the most profits.

These games are believed to be particularly effective in conveying to departmental specialists the realization that no department has independent goals — that all departmental activity is relevant only to the degree that it contributes to the primary goal of net earnings.

The future of the railways very largely depends upon the quality of management which the industry can engender. Most large railways in North America are following systematic programs to upgrade the quality of management. The Canadian National's staff school is an outstanding example of endeavor especially suited to a large railway with wide geophraphical range.

[385. (06 .111]

OFFICIAL INFORMATION

ISSUED BY THE

Permanent Commission
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19, rue du Beau-Site, BRUSSELS.

XVIIIth SESSION — MUNICH (1962).

LIST OF QUESTIONS

for discussion

WITH THE NAMES OF THE REPORTERS.

1st SECTION : WAY AND WORKS.

QUESTION 1.

Adaptation of the methods of laying, aligning and maintaining the permanent way to carry traffic at very high speeds (75 m.p.h. and more) :

a) **on the straight;**

b) **on curves;**

so far as they affect safety and taking into account the type of rolling stock used.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

M. Thille, Ingénieur en Chef à la Division de l'Entretien du Service de la Voie et des Bâtiments de la Région du Sud-Ouest de la Société Nationale des Chemins de fer Français, 1, Place Valhubert, Paris (13e).

America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, New Zealand, Norway, Pakistan, Philippines, South Africa, Siam, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories :

Mr. Kentaro Matsubara, Deputy Director, New Tokaido Line, Construction General Department, Japanese National Railways, 1-1 Marunouchi, Tokyo.

QUESTION 2.

Means of reducing the final cost of signalling installations by standardization or other methods, including the use of electronics and other modern techniques.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

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America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, New Zealand, Norway, Pakistan, Philippines, South Africa, Siam, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories :

Mr. A.W. Woodbridge, Chief Signal Engineer, British Transport Commission, British Railways Division, 222, Marylebone Road, London N.W. 1.

2nd SECTION : LOCOMOTIVES AND ROLLING STOCK.

QUESTION 3.

Latest developments in the braking of railway rolling stock (systems, control, types of equipment, materials used...).

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

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Mr. V.M. KAZARINOV, Docteur en Sciences Techniques, Institut de Recherches des Transports par Chemins de fer, Ministère des Communications de l'U.R.S.S., 3e Mitichtinskaia Ul., Prospect Mira, Moscou I-164.

QUESTION 4.

Safety and automation on electric and Diesel motor power units.

Application of automation techniques in the driving of power units (locomotives and motorcoaches), automatic starting, control of the spinning and skidding of the wheels, automatic transmission of the signal indications and automatic stopping : vigilance and dead-man's devices; application of electronics.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

M. NERUEZ, Ingénieur Principal-Adjoint à la Direction du Matériel et des Achats à la Société Nationale des Chemins de fer Belges, 17, rue de Louvain, Bruxelles.

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Dr. F.T. BARWELL, Electric Traction Engineer (Research), British Transport Commission, British Railways Division, 14, Melbury Terrace, Marylebone, London N.W.1.

3rd SECTION : WORKING.

QUESTION 5.

The economics of railway operation using modern techniques of telecommunications and signalling, taking into account the possibilities offered by electronics to promote automation in :

a) **control of train movements;**

b) **wagon-control;**

c) **centralizing signalling operations (C.T.C.);**

d) **marshalling yards.**

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

Prof. J. Statkiewicz, Chef de Division à l'Institut des Recherches et des Essais Ferroviaires des Chemins de fer de l'Etat Polonais, 86, Ul. Hoza, Varsovie 10.

America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, New Zealand, Norway, Pakistan, Philippines, South Africa, Siam, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent territories :

Mr. L.C. Mohindra, Director, Signalling and Telecommunications, Ministry of Railways (Railway Board), Government of India, New Delhi.

QUESTION 6.

Co-ordination between main line railways and metropolitan or suburban railways (including elevated, underground and other specialized railways). Transfer points (distances, positions, arrangements); lay-out of the lines; town-planning and economic considerations.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

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Dr.-Ing. RECKER, Ministerialrat bei der Hauptverwaltung der Deutschen Bundesbahn, 43-45, Friedrich-Ebert-Anlage, Frankfurt (Main).

4th SECTION : GENERAL.

QUESTION 7.

Application of operational research on the railways with particular reference to the purchase of material and stores, stores management and control of the quality of the purchases; traffic market research, etc.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Viet-Nam and Yugoslavia :

Dr.-Ing. M. NOTARI, Inspecteur en Chef Supérieur au Service des Affaires Générales, Chef du Bureau d'Etudes des Chemins de fer de l'Etat Italien, Piazza Croce Rossa, Rome.

America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, West Germany, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, New Zealand, Norway, Pakistan, Philippines, Siam, South Africa, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories :

Dipl.-Ing. JESSEN, Ministerialrat bei der Hauptverwaltung der Deutschen Bundesbahn, 43-45, Friedrich-Ebert-Anlage, Frankfurt (Main).

QUESTION 8.

Policy and problems relating to the education and training of the staff. Training in safety measures.

Reporters :

Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

M. Stjepan Forgić, Directeur du Service du Mouvement de la Direction Générale des Chemins de fer Yougoslaves, Gregorčičeva ulica nº 4, Beograd.

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Herr Hofrat Dr. Walther Sandig, Generalsekretär der Oesterreichischen Bundesbahnen, 9, Elisabethstrasse, Vienne, I.

5th SECTION : COMPLEMENTARY AND SUBSTITUTE SERVICES.

QUESTION 9.

Co-ordination of rail and road transport-passenger and freight on secondary lines. The elements of the problem. — Balance between road and rail. — Various methods of organisation.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, West Germany, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

M. Victor Bultó, Sous-Directeur de la Red Nacional de los Ferrocarriles Españoles, 32, Paseo del Rey, Madrid.

America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, Netherlands, New Zealand, Norway, Pakistan, Philippines, Siam, South Africa, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories :

Dr. J.P.B. Tissot van Patot, Chief of the Division General Policy, Netherlands Railways, 1, Moreelse Park, Utrecht.

QUESTION 10.

Modern methods for the economical working of secondary lines.

Reporters :

Austria, Belgium, Bulgaria, Cambodia, Congo, Czechoslovakia, Denmark, Ethiopia, France and French Community, Greece, Hungary, Italy, Lebanon, Luxemburg, Morocco, Netherlands, Poland, Portugal and overseas territories, Rumania, Spain, Switzerland, Syria, Tunisia, Turkey, Viet-Nam and Yugoslavia :

M. l'Ing. Enrico TENTI, Inspecteur en Chef Supérieur au Service du Mouvement des Chemins de fer de l'Etat Italien, Piazza Croce Rossa, Rome, and

M. Mario BIANCHI, Inspecteur en Chef au Service du Mouvement des Chemins de fer de l'Etat Italien, Piazza Croce Rossa, Rome.

America (North and South), Australia, Burma, Ceylon, Egypt, Finland, Ghana, West Germany, India, Indonesia, Irak, Iran, Republic of Ireland, Japan, Malaysia, New Zealand, Norway, Pakistan, Philippines, Siam, South Africa, Sudan, Sweden, Union of Socialist Soviet Republics, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories :

M. l'Ing. RÖVER, Direktor bei der Hauptverwaltung der Deutschen Bundesbahn, 43-45, Friedrich-Ebert-Anlage, Frankfurt (Main).

NEW BOOKS AND PUBLICATIONS.

[**621** .3]

Dipl.-Eng. Dietrich ERNST, Erlangen. — **Elektronische Analogrecher. Wirkungsweise und Anwendung**. (*Electronic computers. Operation and application.*) — One volume (6 1/4 × 9 1/2 in) of 316 pages with 227 figures. — 1960, Munich, R. Oldenbourg Verlag, Rosenheimer Strasse, 145. — (Price : cloth binding, DM 38.)

Over the last twenty years or so, electronic computers have undergone a remarkable development. In recent years, attention has mainly been focussed on digital computers (which operate with digital values supplied by operators), due to their spectacular applications to scientific calculations (e.g. rockets) and to administrative management (e.g. in the form of electronic data processing machines). But the older electronic analogue computers (which operate with data supplied by electric voltages which are the images, representations or analogies of the actual data of the problem) have retained their own very extensive field of application where scientific and technical calculations are concerned, e.g. in the sphere of automation and control. That is why the work by D. ERNST — which brings an excellent synopsis of the subject of modern analogue computers, of the difficulties which had to be overcome in constructing them, and of the methods of using them — is all the more welcome as there are, so far, very few works of this kind available, although the technique of these computers is based on a major assembly of units (adders, integrators, multipliers, networks, etc.), and the methods used are already able to benefit from a large pool of experience. In fact, the present work appears to be the first of its kind published in the German language.

Most of the variables are evaluated or measured by analogue means. A new stage is reached when the analogue representations are subjected to mathematical operations. Chapter I of the book recounts the differences between digital and analogue computers, especially as regards methods; it surveys their history and lists the different constituent parts of analogue computers, and their characteristics. The two principal modes of operation of analogue computers, with single cycles or recurring cycles, are explained.

Chapter II deals, in detail, with the different parts of the equipment. It describes the devices used for stabilizing the amplifier gains, such as the limitations in values and frequencies as well as the assemblies and their performance with a view to obtaining experimental retarder functions, proportional integrators, etc. The flexibility of these assemblies is such that they can easily be used to represent nonlinear phenomena, saturation, hysteresis, rest times, starting or propagation delays, etc. For some years, it has also been possible with the aid of electronic assemblies to mutliply two variables with each other.

In contrast to digital computers, the arrangements required for analogue calculations must be specially devised for each case. For the programming of assemblies to be adopted, two principal methods are possible, viz., firstly, the method where the mathematical formulae are used as a guide, and secondly, the method based on the use of block diagrams which reproduce the functions to be carried out. In both cases, the scales must be chosen judiciously in order to avoid unduly low voltages which cannot easily be distinguished from the

interference voltages (circuit noises, etc.), as well as unduly high voltages which would exceed the amplifier saturation limits, etc. In this respect, the book represents a clear guide to the potential user.

It is not sufficient to formulate general directives; it is much better to proceed step by step on the strength of a certain number of examples, and a great number of pages (approx. 600) of the book have in fact been devoted to this purpose. The examples given range from the performance of a spark gap to the calculation of the movement of a contactor armature, passing on to the performance of a low-pass filter, the starting of an asynchronous motor with different resistances, the voltage curve of a synchronous generator with variable load, and the temperature control of a live steam generator.

The book continues with a more detailed analysis of more difficult applications (partial differential equations; systems of algebraic equations) and of special methods (frequency response curves; working in real time; use in combination with digital computers). It also deals with the means which can be used for the representation of special physical relations. It is in this sphere that the analogue computers are irreplaceable. Non-linearities which can only with difficulty be translated into formulas and therefore give rise to very great difficulties when dealt with by digital computers merely call, in the case of analogue computers, for certain precautions and are therefore no more difficult than linear problems.

The book by D. ERNST is completed by a good description of 16 different types of analogue computers, manufactured in Western Germany, Great Britain, France, Switzerland, Japan and U.S.A. Whilst most of them work with electronic valves, some make use of transistors which are less expensive.

The present book must thus be regarded as an excellent high-standard work of instruction, written by an engineer, and published at a time when this type of computers has reached a stage of maturity based on a widening pool of experience. The book can therefore be unhesitatingly recommended.

P. Sch.

3rd International Cybernetic Congress.

We recall to our readers that the International Association of Cybernetics will organise from the 11th to 15th September 1961, its 3rd International Cybernetic Congress, at Namur (Belgium).

The following subjects will be studied : Foundations and methods of cybernetics - Semantic machines - Automation : Technical aspects - Automation : Economic and social aspect - Cybernetics and life.

All those wishing to participate to this Congress are requested to apply to the Secretariat of the Association, 13, rue Basse-Marcelle, Namur (Belgium).

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(MARCH 1961)

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CUOMO (S.). — **Sulla resistenza di travi inflesse di acciaio ad elevate temperature.** (7 000 parole tabelle & fig.)

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MERLINI (R.). — **Il Moncenisio nel collegamento ferroviario fra Italia e MEC.** (4 000 parole & fig.)

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PATRASSI (A.). — **Trasporti rapidi di persone in un'area urbana o metropolitana.** (10 000 parole, tabelle & fig.)

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ANNARATONE (D.). — **Studio della flessione deviata in campo plastico.** (*Continua.*) (3 000 parole & fig.)

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L'esame delle giunzioni saldate mediante gli ultrasuoni. (800 parole & fig.)

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LASSEN-NIELSEN. — **Deas Island Tunnel.** Gezonken verkeerstunnel onder de Fraser River in Canada. (4 000 woorden & fig.)

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1960 **656 .211 (45)**
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STUNNENBERG (J.). — Het **kruispunt van Europa** heeft zorgen. (1 500 woorden & fig.)

1960 **656 .2 (**
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Nogmaals : **De Russische Spoorwegen.** (2 600 wo den & fig.)

1960 **385 .**
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Houdt het personeel op de hoogte! (1 600 woorde

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KARSKENS (J.J.). — **Iets over vier- en zesas materieel.** (1 500 woorden & fig.)

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HUPKES (G.). — Het **merkbeeld van de spoorwe** (1 000 woorden & fig.)

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ROONEY (D.H.). — **Concepção e instalação d equipamento de suspensão.** (1 200 palavras & fig.)

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LEMKOWICZ (A.). — **Pourquoi la traction élec- que ?** (1 500 mots.)

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BORUCKI (T.). — **Les wagons-réfrigérants type 5 L.** 200 mots & fig.)

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KESICKI (Z.). — **L'analyse des dommages causés route aux wagons.** (2 000 mots.)

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JAGIELLO (K.). — **La sécurité du travail dans le rvice de la traction.** (3 300 mots & tableaux.)

1959 **625** .214 = 491 .85
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BALA (Z.). — **Echange de lubrifiant dans les boîtes essieu à rouleaux des wagons.** (1 200 mots.)

1959 **625** .282 (47) = 491 .85
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KRZEMIENIECKI (A.). — Les **nouvelles locomotives** ux Chemins de fer de l'U.R.S.S. (2 300 mots & fig.)

1959 **625** .216 (4) = 491 .85
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A.K. — La question de l'**attelage automatique** dans s chemins de fer européens. (2 400 mots.)

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NIELIWODZKI (J.). — Pour une **meilleure utilisation es locomotives à vapeur.** (2 100 mots, tableaux & fig.)

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KRASNOPOLSKI (B.). — Les **nouveaux autorails Diesel** aux P.K.P. (Chemins de fer d'Etat polonais). 2 200 mots & fig.)

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BLASZCZYK (H.). — **Education des travailleurs du ervice de la traction.** (1 500 mots & tableaux.)

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ZIEMILSKI (A.). — **Locomotives électriques des P.K.P.** (3 500 mots, tableaux & fig.)

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ZAWADA (M.). — Périodicité des **réparations des autorails Diesel.** (1 900 mots, tableaux & fig.)

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KROGULSKI (T.). — **Le problème d'un temps de travail économique dans le matériel roulant.** (900 mots.)

1959 **621** .436 = 491 .85
Przeglad Kolejowy Mechaniczny, septembre, p. 257.
WOLFRAM (T.). — **Influence de la nature de l'alimentation d'un moteur Diesel sur sa résistance.** (2 800 mots & fig.)

1959 **625** .234 (438) = 491 .85
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PIELACINSKI (M.). — Le **chauffage électrique** pour plusieurs tensions de service des voitures Type 7 A aux P.K.P. (3 000 mots & fig.)

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1959 **621** .431 .72 = 491 .85
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KRZEMINSKI (W.). — L'arrêt moyen dans les gares et le **coefficient de rotation des wagons.** (1 200 mots & tableaux.)

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GOLIK (M.). — **La collaboration des gares avec les usines sidérurgiques.** (1 100 mots & tableaux.)

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Przeglad Kolejowy Przewozowy, juin, p. 141.
LASKOWSKI (Z.). — **Les enfants — les colonies de vacances — le chemin de fer.** (1 200 mots & fig.)

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Przeglad Kolejowy Przewozowy, juin, p. 144.
LOZINSKI (E.). — Le **nouveau tarif-voyageurs** des P.K.P. (1 000 mots.)

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KARPINSKI (A.). — L'**électrification** du réseau des P.K.P. et ses perspectives. (1 550 mots & fig.)

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Przeglad Kolejowy Przewozowy, juin, p. 152.
SOSNOWSKI (S.). — **Le transport ferroviaire dans les ports.** (1 000 mots & fig.)

1959 **656** .223 .2 = 491 .85
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KOPEĆ (M.). — **L'arrêt moyen du wagon en gare de triage.** (1 800 mots & fig.)

1959 **656** .28 = 491 .85
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ŚMIGLA (R.). — L'analyse psycho-physiologique des **accidents ferroviaires.** (1 300 mots.)

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CZAYKA (M.). — **Une nouvelle méthode pour pallier les irrégularités de transport.** (1 400 mots & tableaux.)

1959 **656** .227 = 491 .85
Przeglad Kolejowy Przewozowy, juillet, p. 179.
ŚWIDERSKI (F.). — **Marquage des envois de chargement dangereux.** (1 400 mots.)

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SZKÓP et CIESZYŃSKI. — **Défauts des gares de triage.** (1 600 mots.)

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BYELENKI (N.P.). — **Les problèmes économiques de la localisation de la traction électrique et de la traction Diesel.** (2 800 mots, tableaux & fig.)

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ABATKOV (A.) et BYELOKRYLINE (Y.F.). — Emploi de redresseurs semi-conducteurs dans les **sous-stations de traction.** (2 000 mots & fig.)

1959 **621** .3 = 491
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TARTARINOV (B.P.) et ARKHANGUELSK
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GOLOVTCHENKO (G.I.). — **Les moyens pr cipaux d'un travail vraiment économique.** (2 200 mot

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WASSYLYEV (G.S.), LEPNYEV (M.I.)
TIKHONOV (K.K.). — **L'organisation du trafic d trains pendant l'électrification de la ligne.** (1 700 m & fig.)

1959 **656** .222 = 491
Jéléznodoroznyï Transporte, août, p. 51.
PIWENSTEIN (D.I.). — **L'horaire graphique d trains et l'utilisation rationnelle du débit de la lig pendant la réparation des voies.** (3 200 mots & fig

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ORLOV (A.P.), NIKOLAIEV (I.S.) et KARYOU
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1959 **656** .225 = 491
Jéléznodoroznyï Transporte, août, p. 56.
KACHTCHEYEV (N.T.). — **Mécanisation de vidange des produits pétroliers des citernes.** (2 200 mo & fig.)

1959 **625** .26 = 491
Jéléznodoroznyï Transporte, août, p. 70.
ALYEV (M.A.). — **Amélioration des conditions d travail et augmentation de la production dans l'usin** (1 400 mots & fig.)

1959 **656** .2 (498) = 491
Jéléznodoroznyï Transporte, août, p. 80.
SIMULESCU (D.). — Les perspectives du **dévelop pement du transport ferroviaire** dans la Républiqu populaire de Roumanie. (2 900 mots & fig.)

1959 **656** .2 (06 = 491
Jéléznodoroznyï Transporte, août, p. 87.
LIKHATCHEV (W.G.) et STYEPANOV (L.A.). — La IV[e] Session de la **Conférence des Ministres OSShD** (2 400 mots.)

1959 **656** .2 (4) = 491
Jéléznodoroznyï Transporte, août, p. 90.
LE VERT (P.). — L'œuvre du **Comité des Transport Intérieurs** de la Commission Economique pour l'Europe (4 300 mots.)

1959 **656** .2 (4) = 491 .7

léznodoroznyï Transporte, août, p. 93.

SENTYOULEWA (A.A.). — La **collaboration dans domaine des problèmes de transport** sur une base ropéenne. (1 600 mots.)

In Swedish (= 439 .71).

Järnvägs-Teknik. (Stockholm.)

1960 **625** .233 (485) = 439 .71

rnvägs-Teknik, nº 8, p. 191.

RIDAL (F.). — Le **développement de l'éclairage ectrique des trains** aux Chemins de fer de l'Etat édois. (4 000 mots & fig.)

1960 **625** .143 = 439 .71

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STORM (G.). — Quelques observations sur les **contraintes des rails et des éclisses lors des travaux de la voie.** (2 000 mots & fig.)

In Czech. (= 91 .886).

Inženýrské Stavby. (Prague.)

1960 **624** = 91 .886

Inženýrské Stavby, nº 12, p. 457.

FRÝBA (L.). — **Caractéristiques dynamiques des ponts métalliques de chemins de fer.** (4 000 mots, tableau & fig.)

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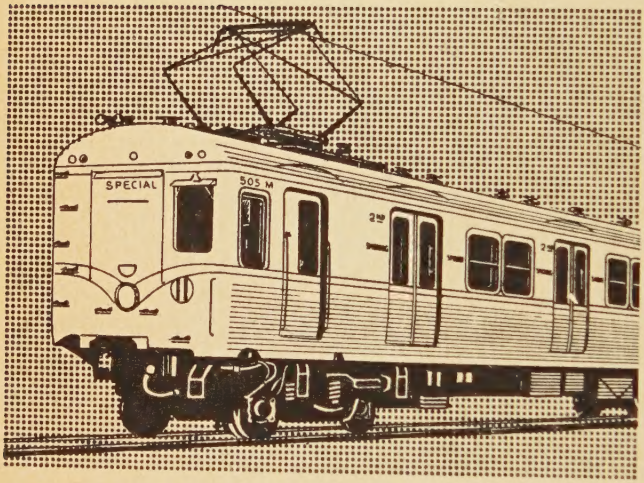
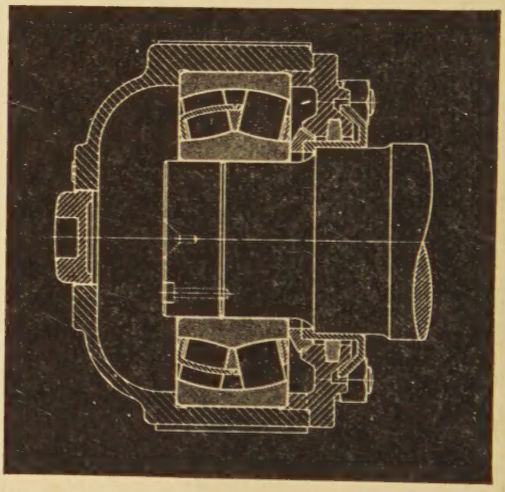
Australian suburban trains with SKF roller bearing axleboxes

Electric multiple-unit trains of the type shown here — in all, 90 motor coaches and 120 trailer coaches — have been put into service on Melbourne's suburban lines by Victorian Government Railways. During peak hours there are seven coaches in each train — three motor and four trailer. In off-peak hours, however, four-coach train sets are used, comprising two motor coaches and two trailer coaches. The maximum speed is approximately 75 m.p.h. and all axles are fitted with SKF roller bearing axleboxes.





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